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A PRACTICAL THEORY OF VOUSSOIR ARCHES. PART II.

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II.

HEIGHT OF SURCHARGE, IN ORDER THAT THE CENTER LINE OF ARCH RING, MAY BE A POSSIBLE CURVE OF PRESSURES.

51. Let it be required to find the proper height from the soffit to the top of roadway, in order that the center line of the arch may be a possible line of pressures.

The black line at the top, Fig 8 shows the line of roadway for the segmental arch of 100′ radius and 4′ depth of keystone, found by the following approximate construction:

Divide the semi arch into nine portions aa_1, a_1a_2, . . . , each of the same horizontal length; the weight of each portion is nearly proportional to its medial vertical line, limited by the soffit and roadway (yet to be found), drawn through the centers c_1, c_2, ... The horizontal $\overline{aA}$ and the line Aa_9 drawn tangent to the center line at a_9 represent the directions of the resultant pressures at a and a_9, assuming the pressure at a_9 to be tangent to the center line. From the point A draw $\overline{A_2}$, $\overline{A_3}$, . . . parallel to c_1, c_2, c_1c_2, ... ; the points of the type c lying in the center of the arch ring; also draw the vertical $\overline{1, 10}$, at such a distance $\overline{A1}$, that $\overline{12}$ is equal to the distance from the soffit at c_1 to the roadway. Then $\overline{23}$, $\overline{34}$, ... are the heights from the soffit to the roadway at c_2, c_3, ... , which may now be laid off as in the figure.

The accurate construction is as follows: the horizontal thrust acting at a must be combined, at the intersection of $\overline{aA}$ with the vertical through c_1, with such a force $\overline{12}$ (force diagram) that the resultant will pass through the center line at a_1. This resultant is, in turn, produced to intersection with the vertical through c_2, where it must be combined with such a force $\overline{23}$ that the resultant $\overline{A3}$ will pass through a_2, and so on; the forces 1..... 10 being thus found and laid off as before. Now, since the resultants at a_1, a_2, ... are tangent, or very nearly tangent for a segmental arch, to the center line, their directions are evidently parallel to the chords $\overline{c_1}$, $\overline{c_2}$, $\overline{c_3}$, $\overline{c_4}$, . . . as assumed in the first construction.

It is seen from Fig. 8, that a lightening of the spandrel walls, about from a_3 to a_9, conduces to stability. This is often done in large bridges. By this means the ignorant mason who built the Pont-y-Tu-Prydd arch of 140 feet span, 35 feet rise and only 1 foot 6 inches depth of rubble arch ring in the body of the arch, managed to cause the bridge to stand; which when first built fell, by the weight of the haunches forcing up the crown.

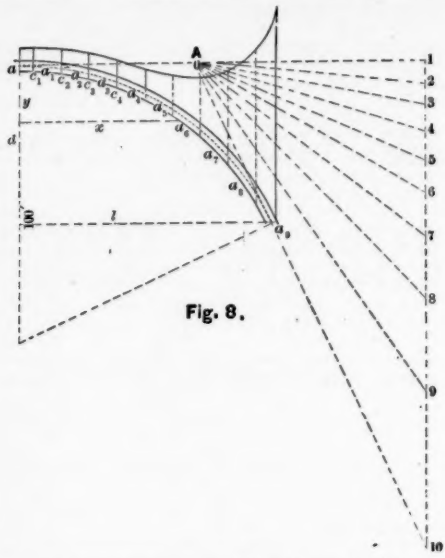

Fig. 8.

On being rebuilt, the spandrels were lightened by cylindrical openings, the spaces between, being filled with charcoal (see VAN NOSTRAND'S MAGAZINE for March 1873, p. 193) and the bridge stands to this day. Though it evidently does not admit of heavy rolling loads, may suffice for a light traffic. As a precedent however, in construction it is to be avoided.

52. On testing a parabolic arch of 200′ span and 100′ rise in the same way, the line limiting the roadway will be found to be everywhere the same vertical distance from the soffit; so that where the surcharge is very high the parabola is the best form of arch ring.

This may be shown analytically, in an easy manner. Thus conceive a_1, a_2 . . . a_9 consist of a thin metallic ring, that is to sustain a uniform horizontal load, w per foot, without bending; required the form of the curve a . . a_9. It is necessary that the line of pressures coincides throughout with the rib, for if it departs from it at any point, the resultant on that point multiplied by its lever arm to that point, gives a bending moment, which the thin rib is supposed incapable of resisting. (See art. 4 Fig. 2.)

Let $\overline{a\mathrm{A}}$ be the axis of X, the vertical down from a the axis of Y. The resultant at a is the horizontal thrust Q. Now take moments of this force, and the downward acting weight on the part aa_6, about a_6, whose coördinates are y and x,

$$\therefore \mathrm{M}=\mathrm{Q}y-\frac{\mathrm{W}x^2}{2}.$$

Now M must equal zero for every point of the arch, in which case *the line of pressures will coincide with the figure of the rib.*

Placing $\mathrm{M}=o$, we deduce,

$$x^2=\frac{2\mathrm{Q}}{\mathrm{W}}y$$

the equation of a parabola, Q.E.D.

53. We see from the foregoing that for a simple arch ring, or for a uniform horizontal load on the ring, and approximately for a very deep surcharge, level at top, the parabola is the best form for the arch ring.

For bridges level at top, at least for bridges whose rise is not over $\frac{1}{3}$ span, the circular is a better form than the parabolic. It is needless to speak of the superiority of the segmental arch over the elliptical and allied forms, whose inherent weakness at the haunches is generally remedied by a greater depth of arch ring, a sufficient reason for choosing

"The rainbow's lovely form"

as the best figure for an arch, however beautiful the elliptical or oval curve may be considered in itself.

54. Fig. 8 will suffice to illustrate the common method, as given by many authors, of binding the curve of pressures. Extend $\overline{a\mathrm{A}}$ to c_1, then draw $c_1c_2 \parallel \mathrm{A}_2$, which is thus the resultant on joint a_1. Extend this resultant to intersection with vertical through c_2, from which

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point draw $c_2c_2 \parallel A_2$ and so on. This method, so simple in theory, does not work well in practice, owing to the fact that any error made in finding any point of the curve of pressures is carried on; whereas by the method given in art. 2, any error made is confined to the joint where it is made. It is evident that by the latter method, using *straight* edged rulers and triangles (steel are the best), feathered edged scales, prickers, hard pencils and smooth paper, that the centers of pressure should be found almost to a very needle point. Such accuracy is moreover essential to properly testing an arch ring. It is well to observe that the constructions can be made by drawing only a very few lines. In fact too many lines only serve to confuse the drawing and should be avoided.

CURVE OF PRESSURES CORRESPONDING TO THE MINIMUM AND ALSO TO THE MAXIMUM HORIZONTAL THRUST IN AN UNSYMMETRICAL ARCH.

55. These cases were not demonstrated for an unsymmetrical arch in Part 1, though they offer no difficulty, and are essential to a complete investigation of the stability of an arch. In Fig. 9, *eca* represents an unsymmetrical arch, or an arch acted on by forces, not symmetrical —vertical or inclined.

Let P = resultant of the external forces, acting on the arch between a and c, not including the reaction R at a. Then on combining $R = \overline{ak}$, with P, we get the center of pressure c on the joint cc_1. Similarly we could proceed for other points b, d, e, of the curve of pressures,

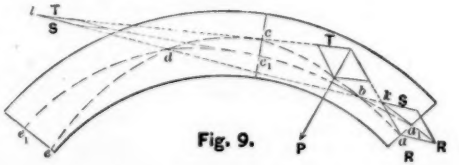


Fig. 9.

corresponding to the resultant $R = \overline{ah}$, acting through a in the direction $\overline{ak}$.

Let $a_1\ b\ c_1\ d\ e_1$ be a second curve, corresponding to the reaction R′ at a_1. Now *if* S *is such a force, acting towards the left, that when combined with* R, *it gives* R′ *as a resultant*, we can find a point c_1, on joint cc_1, of the new curve of pressures, either by combining R′ with P as before, or by combining its components with P: thus call the resultant of R and P, T; this combined at l with S, gives a resultant which cuts joint cc_1 at c_1, *a point lying between* $\overline{kl}$ and c, $\overline{kl}$ being in the direction of s produced.

56. By this construction, it is seen that the new curve of pressures, corresponding to the reaction R′ at a', *passes through* b *and* d the points where kl intersects the first curve of pressures; for other joints, as ee_1, the new curve lies nearer $\overline{kl}$ than the first curve; since when s acts to the left, the combination of T, for any joint, with S gives a resultant acting *between* T and S, which therefore cuts the joint nearer $\overline{kl}$ than the first curve; since when S acts to the left, the combination of T, for any joint, with S, gives a resultant acting *between* T and S, which therefore cuts the joint nearer $\overline{kl}$ than the first center of pressure.

The above supposes that neither R nor S are vertical, but that both act to the left, whence the horizontal component of R′ exceeds that of R. The joints are, moreover, not supposed inclined more than 90° from the vertical counting from the top.

57. *Prop. If two curves of pressure cut each other, the curve which lies nearest the straight line, which joins their common points, corresponds to the greatest horizontal thrust.*

We have seen in the preceding article that the two curves *can only* intersect on the straight line kl (Fig. 10) as implied in the proposition.

Now if, at any joint cc_1, the center of pressure c_1, corresponding to the curve $a_1bc_1de_1$, lies nearer $\overline{kl}$, the straight line joining b and d, than the curve *abcde*, then we may suppose a force S, acting in the direction $\overline{kl}$, to be combined with T at l, to effect it. The force S, thus found, must therefore when combined with R at

a give R′; since R and S produce the some effect as R′; so that all points of the first curve can be found by combining R with the resultant of the forces P, up to the joint, and afterwards combining their resultant with S.

The force S, acting to the left, increases the horizontal component of the resultants on each joint; hence the curve $a_1 bc_1 de_1$ corresponds to greater horizontal thrusts than the curve *abcde*, as stated in the proposition.

If the arch is symmetrical, the curves of pressure are symmetrical with respect to the crown, whence $\overline{kl}$ must be horizontal, whence follows the conclusions of art. 4. Part 1 demonstrated these in another manner.

58. 1/. *If a curve of pressures has two points common to the intrados and an intermediate point common to the extrados, it corresponds to the minimum horizontal thrust.*

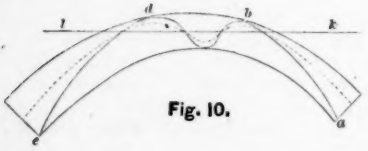


Fig. 10.

Fig. 11.

For, suppose the curve *abcde*, Fig. 10, touches the extrados near *c*, the intrados on both sides nearer the abutments.

Then any other curve of pressures, a_1 bc_1 de_1 that remain in the arch ring, must cut the first, only in points on the straight line $\overline{kl}$, joining any two points of intersection.

Now the new curve, near the points of contact of the first curve with the contour curves of the arch ring, must, if it remains in the arch ring, pass nearer $\overline{kl}$ than the first curve; whence, by *Prop.* art. 57, the first curve corresponds to a less horizontal thrust. Q.E.D.

2/. *If a curve of pressures abcde, Fig.* 11, *has two points of contact b and d with the extrados, and an intermediate point of contact c with the intrados, it corresponds to a minimum horizontal thrust, if bcd, in the vicinity of c, lies between the intrados and the straight line* $\overline{bd}$.

For any other curve, lying in the arch ring, as the dotted curve, *must* lie nearer the straight line *kl*, joining their points of intersection, than the first, in the vicinity of *b c* and *d*, and thus corresponds to a greater horizontal thrust.

3/. *If however, the intrados, in the vicinity of c lies between the curve bcd, Fig.* 12, *and the straight line* $\overline{bd}$, *the curve corresponds to a maximum horizontal thrust;* since this curve lies nearer $\overline{kl}$ than any other as the dotted curve of pressures.

It is seen that $\overline{kl}$ in Fig. 11 lies above $\overline{bd}$, whereas the reverse occurs in Fig. 10.

59. When a curve of pressures possesses both the properties of the maximum and minimum of the thrust, the arch is at the limit of stability; as see all the figures relating to the experiments in Part I. The above principles were first stated by Dr. Hermann Scheffler.

60. When the arch is symmetrical, the curves of pressure are so, whence follow the conclusions of arts. 5 and 6 of Part I, including the cases not there demonstrated. The second case of the minimum is but rarely, if ever, found in practice; and of course does not occur when the first case obtains.

61. For the mature hypothesis of incompressible voussoirs, that curve of pressures which corresponds to the minimum of the thrust is, by the principle of the least resistance, the true one.

We have previously explained in art. 27 how this principle is modified for materials used in practice, both by their compressibility and by the cutting of the stones.

We infer, from the reasoning in art. 27, that with well fitting stones and unyielding abutments, that the actual line of pressures in an arch is found within limits, approximately equidistant from the center line of the arch ring, and having the characteristics of both the max. and the min. of the thrust within those limits. Thus in Fig. 12, the dotted line represents the actual line of press-

ures within the limits drawn, since the part *abc* corresponds to the max. and *bcd*

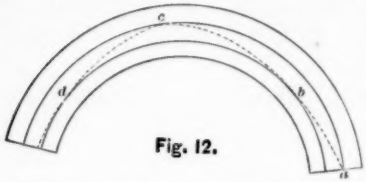


Fig. 12.

to the min. of the thrust within those limits; for *b* lies above a straight line drawn from *a* to *c* (art. 58, /3), and *c* lies between *b* and *d* (art. 58, /1). If the abutments yielded however, the true curve is found within wider limits, and simply corresponds to the min. of the thrust within those limits (see art. 28).

In view however of the influences of temperature, not fitting the stones perfectly, yielding of piers and abutments and shocks, it is recommended to require *in designing an arch*, that for any position of the rolling load, the max. and min. line of pressures may be drawn within somewhat narrower limits than the middle third, otherwise increase the depth an amount, to be left to the judgment of the engineer, as suggested in art. 29.

PRESSURES PER SQUARE UNIT IN EXISTING BRIDGES.

62. By computation, it is found, that in existing bridges, the pressure per square foot on the voussoirs at the crown, *supposing this pressure uniformly distributed*, varies from less than one ton per square foot, for the smallest arches, to 20 tons per square foot and over, for arches of 150 to 200 feet span; the strains being estimated for dead load only.

The normal pressure per square foot at the abutment is greater, often three or four times the above.

It is thus the practice to increase the unit strains with the span.

The material should not be strained at the most compressed edge more than one fifth the crushing weight. Therefore, at the joints of rupture, where the resultant is supposed to pass one-third depth joint from an edge, and the pressure per square foot at the most compressed edge is *double the mean*, the material should not be strained to more than one-tenth the crushing weight, *if* the pressure is supposed uniformly distributed. On this supposition, if we take the crushing weights of sandstone, limestone and granite (which vary between wide limits) as 300, 400 and 500 tons per square foot, respectively, the allowable strains at the most compressed edges will be 30, 40 and 50 tons. If weaker materials are used the unit strains must be less, and we should increase the depth of voussoirs.

If the curved courses of bricks are in concentric rolls, without bond, the determination of the line of pressures, as well as the distribution of the pressure on each course, becomes uncertain and indeterminate. As a rough guess, if there are n rolls, each roll may be supposed to be $\frac{1}{n}$ of the pressure. As the outer roll has the greatest span, it is only necessary to test its stability under $\frac{1}{n}$ the total load. It is not recommended, though, to trust to any such rule, but to bond the rolls, using strong cement; so as to approximate the structure to a "rigid arch."

ARCHES WITH VERTICAL AND HORIZONTAL LOADS.

63. In the arch ADB, Fig. 13, suppose it required to pass a curve of pressures through the points A, E and B.

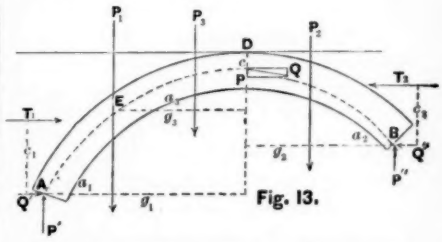


Fig. 13.

Let C be another point of this curve, at the crown, where the horizontal component of the pressure is Q, the vertical component P. Call the vertical components of the loads on the segments AD, DB and ED, P_1, P_2, P_3, respectively; their *horizontal* components T_1, T_2, T_3, respectively.

Call the perpendicular distances from P_1 and T_1 to A, a_1 and c_1; from P_2 and T_2 to B, a_2 and c_2; and from P_3 and T_3 to E, a_3 and c_3, respectively.

Also call the vertical distances of C' the point of application of the inclined thrust at the crown, above A, B and E, b_1, b_2 and b_3, respectively; and the horizontal distances of the same points A, B, E, from the crown, g_1, g_2 and g_3.

64. We now take moments in turn about A, B and E. In eqs. (9) and (11), we suppose the arch to the right of the crown removed, and its effect replaced by the resultant of P and Q acting to the left, P being + when acting upwards; in eq. (10), the part left of the crown is supposed removed and a force equal and directly opposed to the resultant of P and Q acting to the right. We thus find:

$$a_1P_1-g_1P+c_1T_1=b_1Q \quad \ldots . \quad (9)$$
$$a_2P_2+g_2P+c_2T_2=b_2Q \quad \ldots . \quad (10)$$
$$a_3P_3-g_3P+c_3T_3=b_3Q \quad \ldots . \quad (11)$$

Equating the values of Q in (9) and (10), we find,

$$P=\frac{b_2(a_1P_1+c_1T_1)-b_1(a_2P_2+c_2T_2)}{b_2g_1+b_1g_2} \quad \ldots \quad (12)$$

From (9) we obtain,

$$Q=\frac{a_1P_1-g_1P+c_1T_1}{b_1} \quad \ldots . \quad (13)$$

These equations suffice to determine P and Q, when the position of C is known. When, however, we can only locate the points A, E and B, the values of P and Q and the position of C is found as follows.

For convenience let us make the following abbreviations:

$$g_2+g_3=d_1, \quad g_1-g_3=d_2, \quad g_1+g_2=d_3,$$
$$b_2-b_3=e_1, \; b_1-b_3=e_2, \; b_1-b_2=r.$$

Now subtract (10) from (9),

$$a_1P_1-a_2P_2-Pd_3+c_1T_1-c_2T_2=Qe_3. \quad (13a)$$

also, subtract (11) from (9)

$$a_1P_1-a_3P_3-Pd_2+c_1T_1-c_3T_3=Qe_2.$$

Equating the values of Q drawn from these last two equations, and noting that

$$a_1P_1(e_2-e_3)=a_1P_1e_1; \; c_1T_1\,(e_2-e_3)=c_1T_1e_1$$

we have,

$$P=\frac{e_1(a_1P_1+c_1T_1)-e_2(a_2P_2+c_2T_2)+e_3(a_3P_3+c_3T_3)}{e_2d_3-e_3d_2} \quad \ldots \quad (14)$$

Substituting in eq. (13*a*) the value of P just found, reducing the terms of one member to the same denominator, collecting like terms, whose coefficients are of the type *ed*, and noting that, $e_2-e_1=e_3$ and $d_3-d_2=d_1$, we have,

$$Q=\frac{d_1(a_1P_1+c_1T_1)+d_2(a_2P_2+c_2T_2)-d_3(a_3P_3+c_3T_3)}{e_2d_3-e_3d_2} \quad \ldots \quad (15)$$

From (9), we have,

$$b_1=\frac{a_1P_1-g_1P+c_1T_1}{Q} \quad \ldots \quad (16)$$

to fix the position of C at the crown.

We have always for the reactions at A and B, $P'=P_1-P$, $P''=P_2+P$, $Q'=Q-T_1$, $Q''=Q-T_2$.

65. The above equations apply directly to unsymmetrical arches, solicited only by vertical forces by making T_1, T_2 and T_3 zero. Compare Part 1 art. 12.

When the arch and load is symmetrical, P=O. If the point of application at the crown is known, we have from (13),

$$Q=\frac{a_1P_1+c_1T_1}{b_1} \quad \ldots \quad (17)$$

If two points A and E are given, we have then $g_1=g_3$, $h_1=h_3$, $d_3=2g_1$, $e_3=o$ $P_1=P_3$, $T_1=T_3$, $a_1=a_3$, $c_1=c_3$; whence from (15),

$$Q=\frac{a_1P_1+c_1T_1-(a_2P_2+c_2T_2)}{e_2} \quad \ldots \quad (18)$$

The position of Q is then found from (16) by making P=*o*.

Eq. (18) is very easily deduced independently.

66. *Application to Underground Arches.*

Let Fig. 14 represent a culvert, with the embankment above it partially completed; so that when the material of the embankment is reduced to the same specific gravity as that of the arch, a line $\overline{ai}$ will limit its top; the earth being level to the left of *a* and to the right of *i*.

If the surcharge is of the same specific gravity up to *bh*, as the voussoirs, then if the earth has a natural slope, the line $\overline{ai}$ will be straight, as drawn; otherwise it may be curved.

The tables for the *vertical forces* are made out as usual. The mean heights of the trapezoids are represented by the dotted lines and the sum of the first

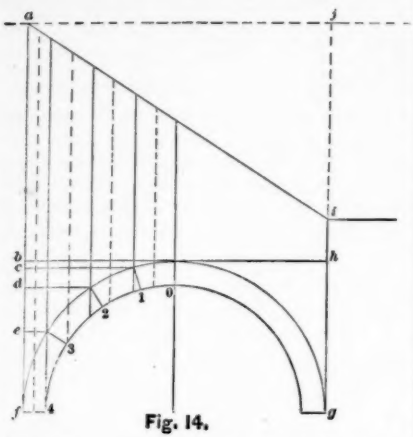


Fig. 14.

three trapezoids will be considered as the surface from the crown to the third joint; similarly for other joints.

This is a sufficiently near approximation for a deep surcharge. For greater accuracy the method detailed in art. 31 may be used.

The horizontal forces are due to the earth pressure and are very difficult to estimate exactly. In a mass of earth with an *unlimited level surface*, the horizontal pressure per square unit at a depth x*

$$p = wx\frac{1-\sin.\ \Phi}{1+\sin.\ \Phi} = wx\ tan.^2\ (45^\circ - \tfrac{1}{2}\Phi).$$

When the upper surface is at the angle of repose Φ, the pressure per squre unit, parallel to the slope, is,

$$p' = wx\ \cos.\ \Phi.$$

w represents the weight per cubic unit of the earth.

These formulæ are modified, when the earth is not of unlimited extent, the friction of the abutting surfaces causing a change in the direction of the pressure.

Again, the surface above is sloping from a to i, and level elsewhere.

Cohesion, likewise plays an important *role* in earth pressure; its influence becoming much more marked as the embankment grows older. For new embankments it is well to neglect it.

Let us assume, as an approximation, that the horizontal pressures, due to the earth, on voussoirs 1, 2, 3 and 4, are due to the heights x measured along the dotted lines from the extrados of each voussoir to the surface of level topped earth.

The surfaces against which these pressures act for voussoirs 1, 2, 3, 4, are, $\overline{bc}$, $\overline{cd}$, $\overline{de}$, $\overline{ef}$, respectively; so that the horizontal pressure acting on the third voussoir, for instance, is equal to the product of the height de, by the height of the surcharge from the extrados to the surface, by $tan^2\ (45-\frac{1}{2}\Phi)$, ($w$ being taken as unity). In the following examples let $\Phi=30^\circ$, so that, $tan^2\ (45-\frac{1}{2}\Phi)=\frac{1}{3}$.

The horizontal pressure then upon the third voussoir is, $\overline{de}\times x\times\frac{1}{3}$. It may be written $\frac{yx}{3}$ for any voussoir. The lever arms of these forces, about the top of the arch, are the vertical distances from the line $\overline{bh}$ to the middle of the segments $\overline{bc}$, $\overline{cd}$, $\overline{de}$ and $\overline{ef}$. The moment of these forces, down to any joint, divided by the sum of the same forces, gives the vertical distance from the line $\overline{bh}$ to the resultant of the forces taken, as given in the last column of the following tables concerning horizontal forces.

67. *Example.*—Let the span of the semi-circular culvert be, 11.30 units of length, the depth of voussoir 0.94, the height $\overline{ab}$ of the reduced surcharge 25.12, and the height $\overline{hi}$, 12.56. The billing up to $\overline{bh}$ is taken of the same density as the voussoirs. If the backing was solid up to $\overline{bh}$, the horizontal forces would be due more nearly to the depth from a to the voussoirs on the left, and from i on the right.

Each of the semi-arcs with its load is divided, as shown in Fig. 15, into eight parts (approximate trapezoids), of which the first six have a width of 0.94, the two last a width of 0.47.

In the following table for vertical forces, column (1) gives the joint, columns (2) and (3) the force from the crown to the joint and its lever arm, respectively, for the left semi-arch, columns (4) and (5), giving the same quan tities for the right semi-arch:

* See Rankine's Civil Engineering, p. 332.

Joint.	Left Side.		Right Side.	
	Force.	Lever Arm.	Force.	Lever Arm.
(1)	(2)	(3)	(4)	(5)
1	18.98	0.47	18.25	0.47
2	38.99	0.95	34.07	0.93
3	60.24	1.45	50.98	1.39
4	82.79	1.95	67.57	1.85
5	106.87	2.47	84.16	2.31
6	133.23	3.01	101.28	2.79
7	147.84	3.29	110.58	3.05
8	162.63	3.57	119.68	3.29

The next table refers to the horizontal forces; column (1) referring to the joint, column (2) gives the product $\frac{1}{2}yx$ (see art. 66), column (3), its lever arm about the summit, column (4), the moment, columns (5), (6) and (7) the sum of the forces down to any joint, their moment and the distance of their resultant below the line $\overline{bh}$, respectively.

Joint.	Left Side.			Horizontal Forces.		
	Force.	Lever Arm.	Moment.	Force.	Moment.	Lever arm.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	0.58	0.05	0.03	0.58	0.03	0.05
2	1.29	0.19	0.25	1.87	0.28	0.14
3	2.73	0.47	1.28	4.60	1.56	0.34
4	4.35	0.94	4.09	8.95	5.65	0.63
5	6.37	1.62	10.33	15.32	15.98	1.04
6	11.09	2.64	29.28	26.41	45.26	1.71
7	9.40	3.77	35.44	35.81	80.70	2.25
8	23.46	5.43	127.39	59.27	208.09	3.51
	59.27		208.09			

Columns (1), (5) and (7) are next given for the right side.

Joint	Right Side.		Joint	Horizontal Forces.	
	Force.	Lever Arm.		Force.	Lever Arm.
(1)	(5)	(7)	(1)	(5)	(7)
1	0.59	0.05	5	11.56	0.99
2	1.64	0.14	6	18.51	1.62
3	3.80	0.33	7	24.17	2.12
4	6.96	0.60	8	38.25	3.34

Now let it be required to pass a curve of pressures, 0.41, below the top of the crown joint, and through the lower middle third limits, at joints six on either side.

Now the vertical loads from the crown to joints six on left and right are (see table) $P_1=133.23$, $P_2=101.28$; the distances of their resultants from the vertical through the crown are 3.01 and 2.79 respectively; whence by measurement on the drawing, $g_1=g_2=5.1$ and $a_1=5.1-3=2.1$, $a_2=5.1-2.8=2.3$.

Similarly,

$$T_1=26.41,\ c_1=3.5-1.7=1.8$$
$$T_2=18.51,\ c_2=3.5-1.6=1.9$$

whence by eq. 12, art. 64,

$$P=\frac{a_1P_1+c_1T_1-(a_2P_2+c_2T_2)}{2g_1}=5.8$$

Also by eq. (13), Q=96.

Now lay off on vertical lines, $\overline{08}$, to left and right of the center, the numbers in columns 2 and 4 respectively, being the vertical loads from the crown to the joints in order. From columns (3) and (5) of the same table lay off the distances, on the horizontal through the summit, from the crown to the centers of gravity of the vertical loads in order. Thus $\overline{S6}=3.01$ corresponding to $P_1=133.23$.

Next, from the tables referring to horizontal forces, lay off on the horizontals $\overline{08'}$, the forces given in columns 5, for the left and right side respectively. Also lay off on vertical lines the numbers in columns (7), measuring from the line $\overline{gS}$. Thus the total horizontal earth thrust from the crown to joint 8 on the left is $T_1=26.41$; and its point of application is $\overline{g6}=1.71$ below the summit. To find the thrust at the crown, lay off $\overline{mn}=Q$ horizontally, and $\overline{no}=P$ vertically downwards: $\overline{mo}$ is then the resultant at the crown joint in position and magnitude. Draw the lines $\overline{44''}$, $\overline{55''}$... parallel and equal to $\overline{mo}$. Now, to find the center of pressure on a joint, as the 6th on the left, draw vertical and horizontal lines $\overline{6b}$, $\overline{6b}$, through the points of application of P_1 and T_1, to the intersection b; which is thus the point of application of the resultant of P_1 and T_1, represented by the line $\overline{66'}$ in the force polygon on the left. From b draw $ba \parallel \overline{66'}$ to inter-

section a with $\overline{mo}$ produced; from a draw $\overline{ac} \parallel \overline{6'6''}$ to intersection with joint 6 at its center of pressure. It is evident that the resultant there is represented by the line $\overline{6'6''}$, the resultant of $\overline{06}$, $\overline{06'}$ and $\overline{66''}$, or of P_1, T_1 and the inclined thrust at the crown; similarly on the right side, to find the position of the resultant on joint 8, we find d, 3.29 to the right of S and 3.34 below it; thence draw $\overline{de} \parallel \overline{88'}$ to intersection e with $\overline{mo}$ produced; thence draw $\overline{ef} \parallel \overline{8'8''}$ to f the required point; the magnitude and direction of the resultant being represented there by the line $\overline{8'8''}$.

The line of pressures thus found, represented by the dotted line, leaves the middle third at joints 4,5 and 8 on the right, and at joint 8 on the left.

By raising the point m nearly to the upper middle third limit, and the center of pressure at joint 5 on the right to the lower middle third limit, the curve of pressures will remain within the inner third except near the abutment. The arch stones should be increased in depth there, up to about joints 6.

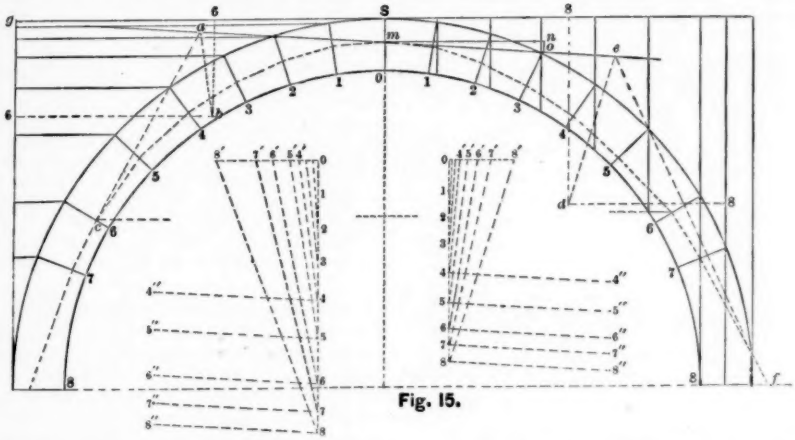


Fig. 15.

The earth is next supposed *level at top*, the distance $ba=hj$, fig. 14, being 25.12 units. On making out a table of vertical and horizontal forces as before, for one side only, we find from eq. (17), art. 65, $Q=122.2$ cubic units of stone, on passing a curve of pressures through the upper middle third limit at the crown and the lower middle third limit at joint 6.

The curve thus found keeps everywhere in the middle third except at joints 8, where it nearly reaches the extrados.

68. If the arch stones are not increased in depth near the abutment, joint 8 will tend to open at the intrados; but this it cannot do unless the haunches spread; which is in turn resisted by the spandrels; or if there are none, by an increased horizontal thrust which the earth is capable of putting forth, thus keeping the line of pressures within the arch ring, *e.g.*, within the middle third if the deformation that the earth permits is small.

Experience shows that very thin arch rings, built in rubble, often can fulfill the conditions of stability when embanked over carefully; the centers being struck after the embankment is mostly completed.

In such cases the earth must exert larger horizontal forces, than given above; so that it is well to be guided mainly by experience in designing underground arches as before remarked.

By increasing the depth of arch stones near the abutment, as suggested, we are safe in presuming on stability without the aid of extra horizontal forces over the ordinary active earth thrusts (see art. 50).

69. The dimensions of the preceding culvert and surcharge may be taken in any unit as feet, meters, etc.

If the unit taken is the meter it corre-

sponds to a railroad culvert at Schwelm, the top of the embankment being 31.^{m}40 above the top of the arch, corresponding to a weight 25.^{m}12 high of materials as dense as the voussoirs, as given by Scheffler. From the diagram for the earth level at top, we find that the normal components of the pressure on joints 6 and 8 are about 180 cubic meters of stone; so that, if uniformly distributed, the pressure per square meter would be $\frac{180}{0.94}$=192 cubic meters of stone.

If we take the weight of a cubic foot of stone at 140 pounds (very low), since there is about 35 cubic feet in one cubic meter, 192 cubic meter=140×35×192 pounds=448 tons. This pressure being on one square meters=10.8 square feet, the pressure per square foot=41.5 tons. If the line of pressures, at joints 6 and 8, is $\frac{1}{3}$, $\frac{1}{4}$ depth joint from edge, the pressure per square foot at the most compressed edges is 83, 111 tons respectively (see arts. 21, 22).

If the material is nowhere to be subjected to more than $\frac{1}{8}$ the crushing weight, it is evident that the best granite or limestone should have been employed in this bridge, having a crushing weight of 400 to 500 tons per square foot. It is stated that the material was not of a good character, and that a large number of voussoirs in all parts of the arch were crushed in consequence.

If the unit of length taken is the foot in the preceding example, we see, that a semi-circular arch of 11.3 feet span, and 1 foot depth of voussoir, is stable against rotation, when the top of the embankment is about 30 to 40 feet above the crown, provided the voussoirs are increased in depth towards the springing, say to 2 feet. The normal pressure now on joint 6 is 180 cubic feet stone=11.3 tons per square foot. At the most compressed edge the pressure is 22.6, if no joint opens, which even sandstone can very well stand.

Any multiple of these dimensions, as 22′.6 span, 2′ depth voussoir and 60′ to 70′ height of surcharge, will show equal stability against rotation. The thrust is now 180 cubic units of stone=1440 cubic feet of stone=90.4 tons. This acts on a surface of 4 square feet; so that the uniform compression is 22.6 tons and the compression at the edge of joint 6 is 45.2 tons about; which sandstone can again bear.

70. It is evident that the height of surcharge should be considered in designing culverts; though it is neglected in the practical formulæ proposed by some authors.

Trautwine (Engineers' Pocket Book p. 347) says:

We have known nearly semicircular arches of 30 to 40 feet span, to be thus built successfully (*i.e.*, when the centers are left standing until the earth-filling is completed above the culvert) with scarcely a particle of masonary above the springs to back them." He recommends *not to do less*, and that only in small spans, than make the height of backing above the springing over the abutment, $\frac{1}{4}$ the total height of the arch from the springing to the top of keystone; and from the point so found to draw a tangent to the arch to limit the backing. As suggested above, it is still better to increase the depth of voussoirs towards the abutment.

Rankine well suggests that "over the arches of culverts, the earth rammed in thin layers should rise to at least half the height of the proposed embankment; the remainder may be tipped in the usual way."

71. It is more than probable that in culverts, where the loose earth is peposited after the culvert is built, especially if the centers are not struck until the embankment is completed over the arch, that the *entire height* of surcharge *does not* press upon the culvert. Cohesion and friction both influence the result. Thus if the grains of earth had the cohesion of stone, the *slight sinking of the culvert*, due to its compressibility, would relieve it of part of the load above it, especially in small culverts. The same sinking would cause a portion of the weight above the arch to be transmitted by friction to the sides.

Thus let s=span of culvert, h=height of surcharge above its top. Now the horizontal pressure of the earth at a depth x on a surface $\triangle x$ being, $wx\tan.^{2}(45°-\frac{1}{2}\Phi)\triangle x$ nearly, the limit of the sum of quantities of this type between the limits, $x=h$ and $x=o$, $=\frac{Wh^{2}}{2}\tan.(45°-\frac{1}{2})\Phi$, is the total horizontal earth thrust exerted on a vertical plane 1 foot wide and h deep below the surface.

If the culvert were suddenly removed, the mass above, if it had no friction or cohesion, would, like a perfect fluid fall, the top surface changing to a lower level. Now consider friction alone, its coefficient being called f=tan. Φ. The weight of the mass above the arch is, wsh; the friction of the vertical paral-

lel walls on either side is $2f\frac{wh^2}{2}\tan.^2(45°-\frac{1}{2}\Phi)$

Now if the arch yields somewhat, the weight still sustained by it is the difference between these expressions.

There is no weight sustained by the arch for,

$$h=\frac{s}{f\tan.^2(45°-\frac{1}{2}\Phi)}$$

and for one half this height, the difference above gives the maximum weight sustained by the lowered arch.

Thus if $s=15$ feet and $\Phi=34$, there is no weight on the arch for $h=75$ feet; the maximum load obtains when $h=37\frac{1}{2}$ feet. In the first case, the weight above the arch is entirely spread to one side.

In reality the lower particles descend, as in a beam, so that a wedge-shaped mass would probably fall down, the material above forming a natural arch. This often happens in brick walls with arched openings in them; the arch yielding so that a natural arch is formed above it, and as a consequence the arch does not sustain the whole weight of surcharge. This happens over every lintel or other compressible support at the top of windows doors etc. in the walls of houses, churches, etc.

The analysis above is given only to illustrate partially the principle enunciated, and not for use in practice.

72. The weight resting on a culvert is not that due to the total height of surcharge for another reason. Draw the trapezoidal cross section (perpendicular to the roadway) of the embankment, and divide it by a vertical line into two equal parts. In consequence of the symmetry the earth thrust of one-half of the slice shown by the cross section (supposed to have any width) against the other half, is horizontal. On combining this thrust with the weight of one-half of the slice acting at its center of gravity, the resultant of course strikes the base farther from the center than if there were no horizontal thrust. Its effect is evidently to increase the vertical pressure towards the slopes and diminish it near the center of the cross section, Q.E.D.

It is not considered advisable to proportion large culverts for a less weight than that due to the whole surcharge; but small drains may be made smaller than such theory requires.

73. *The abutments* of culverts are treated in the graphical construction exactly as though they were a part of the arch. The horizontal thrust of the earth on their outside is not always that due to the height of surcharge, as the ground generally rises abruptly from the foundation of the abutment walls.

It is best, then, to estimate for both cases: the earth pressing and not pressing against the back of the culvert. Again, as part of the weight above the arch is transmitted to the sides, the weight sustained by the abutments may be increased; also the horizontal pressures acting on them and the arch. It is best to err on the same side in designing these structures.

74. *Tunnel arches.*—In treating tunnel arches, only a part of the weight above them is supposed to press on the arch, the balance being transmitted to the sides. Cohesion now plays the most important part. Tunnels have been executed, even in clay, that have stood for some time without support. In such tunnels large masses often fall in, completely choking up the tunnel; so that if an arch of wood, stone, or other material was built before the fallen mass lost its cohesion it would eventually have to support all, or a part of its weight. What weight presses on a tunnel arch cannot be estimated; we can only resort to experience here.

Rankine gives the following formula, founded on practice, for the minimum thickness, t of tunnel arches,

$$f=\sqrt{.12\,r},\ r=\frac{a^2}{b^2};$$

where a=rise and b=half span.

"This is applicable where the ground is of the firmest and safest kind. In soft and slippery materials, the thickness ranges from $\sqrt{.27r}$ to $\sqrt{.48r}$."

75. The *arch* is peculiarly adapted for a tunnel support; for it is the great advantage of the arch, that it *will not be forced in* at one place *without it is forced out* at another. The latter, the enveloping mass generally prevents, if stones and earth are packed in tight back of the arch; so that the arch so constructed should generally stand unless crushed from a too heavy load.

As in practice, tunnel arches are not thus crushed, we may infer, as stated before on theoretical grounds, that only a part of the superincumbent material presses on them. In every deep tunnel, the thickness of the arch ring is not increased over that due to a compara-

tively small height, as is inferred from the preceding formula.

If a quicksand is encountered on one side or the other, the curvature of the arch must be sharply increased there, or the arch may be forced in, as has happened in certain treacherous clays.

76. Assuming the preceding formulæ for earth thrust and the depth of surcharge that is supposed to press, in accordance with this theory, the stability of a tunnel arch is investigated as previously explained in the case of culverts.

Thus take the tunnel arch under the Thames, Fig. 16; whose dimensions in meters are as follows: the thickness of the arch ring is about 0.94, the radius of the upper part $\overline{0..6}$ is 2.16, and of the inferior part $\overline{6..10}$, 8.61 meters; the upper part being formed of three concentric rolls without bond.

The earth and water above the tunnel is supposed to exercise upon the arch a pressure corresponding to a load $7^{m}.54$ high of material like that of the voussoirs; the reduced surcharge being supposed level at top for simplicity.

The upper part of the arch is divided into six parts, having widths of 0.90, 0.63, 0.63, 0.31, 0.31, 0.31, respectively. The lower part is divided into four parts, having lengths, along the center line, 0.47, 0.76, 0.75 and 0.94 respectively and whose lever arms are the distances of their centers of gravity from the vertical axis of the tunnel, or from the horizontal through the top of the arch, for the vertical or horizontal forces respectively. The tables are made out as in art. 67. If preferred, the voussoirs and surcharge may be considered separately as in art. 31, to attain greater accuracy; but the usual method elsewhere followed is sufficiently near for the object in view.

The method followed is moreover as correct for voussoirs 7 to 10 as the one followed in art. 31, since the particular division of the arch preceding any voussoir is immaterial as concerning that voussoir.

In the following condensed table the first column gives the joint, the next the vertical force on that joint counting from the crown, the third column its lever arm counting from the vertical through the crown; columns 4 and 5 give the horizontal force (acting on the extrados of the arch from the crown to the joint considered) and its lever arm about the top of the arch respectively.

Joint.	Vertical Forces.		Horizontal Forces.	
	Force.	Lever arm.	Force.	Lever arm.
1	7.67	0.45	0.38	0.075
2	13.25	0.77	1.11	0.22
3	19.24	1.11	2.45	0.47
4	22.54	1.28	3.54	0.66
5	25.84	1.46	5.40	0.99
6	29.14	1.60	9.38	1.63
7	29.58	1.64	11.08	1.89
8	30.29	1.66	14.23	2.35
9	30.99	1.68	17.39	2.82
10	31.87	1.70	22.49	3.49

To pass a curve of pressures through the upper middle third limit at the crown and the lower middle third limit at joint 5, we have by measurement and from the tables,

$$Q = \frac{aP^{s} + cT_{s}}{b} = \frac{.79 \times 25.84 + 1.02 \times 5.40}{1.69} = 15.34.$$

Now lay off the line of vertical loads, $\overline{0\ .\ .\ 10}$, from column 2, and the line of horizontal forces, $\overline{0\ .\ .\ 10'}$ from column 4.

Next, on the horizontal, through the summit, lay off the lever arms in column 3; and on the vertical, tangent to the extrados, the lever arms in column 5; also from each point, 3′, 4′, 5′, . . . lay off to the right $3'\ 3''$, $4'4''$, $5'5''$, . . . , each equal to Q.

To find the resultant of the presssure on any joint, as the 7th, we draw $\overline{7a}$, $\overline{7a}$, representing the positions of the vertical and horizontal forces ($\overline{07}$, $\overline{07'}$, force diagram) to intersection a; from a draw $\overline{ab} \parallel \overline{77'}$ to intersection b with Q prolonged; at b draw $\overline{bc} \parallel 77''$ to intersection c with joint 7, which is thus the center of pressure on that jont. The resultant on joint 7 is represented by the line $77''$ of the force diagram, being the resultant of $\overline{07}$, $\overline{07'}$ and Q.

The line of pressures thus found is represented by the dotted line, and leaves the inner third of the arch ring at joints 9 and 10. It does not follow that the

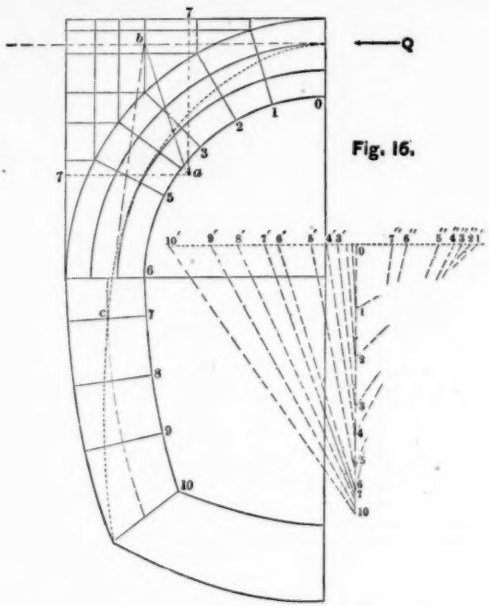


Fig. 16.

arch is unstable. The active forces may not be, and probably are not, as estimated. Whether this be so or not, the joint 10 cannot open inside without the arch being forced out at the haunches; but this, if the earth is packed tight around the arch, is resisted by the earth outside, which there exerts a larger horizontal force than estimated (partly passive), and thereby restricts the line of pressures to narrow limits.

It is thus evident that the arch is stable unless the surrounding earth itself gives way, which will generally not happen. The surrounding mass thus plays the part of spandrel, besides exerting an active thrust, being the least thrust it is capable of. It is even more effective than a spandrel, since it can prevent the crown from rising, which, in stone viaducts, is one method of rupture which the spandrel actually aids in producing.

77. The above construction applies when the rolls of the arch are bonded together. As this is not true in the present case, the problem of determining the true line of pressures becomes impossible of solution.

If we conceive one-third the vertical and horizontal forces, given in the previous table to act on each roll, we shall find that for the outer roll that a curve of pressures cannot be drawn within the middle third, though one can be drawn within the arch ring from the crown to joint 6.

However, the passive earth thrust in good earth will again prevent deformation and thus cause stability as before; but the arch cannot be considered as strong as if it were bonded throughout so as to act as one mass.

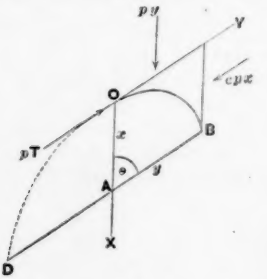
78. The reversed arch at bottom is not supposed to exert any horizontal force, so that the sides of the arch simply rest on it, as though it was an abutment. Otherwise it is used to prevent a forcing in of the sides; and the sum of its horizontal component and that at the crown equal the total horizontal thrust of the earth or fluid on one side.

79. The curve of pressures shown in fig. 16 resembles somewhat a *quarter ellipse*; so that if such a curve was taken for the center line of a tunnel arch, a curve of pressures might be drawn very nearly following this center line; so that if the arch was really acted on by the forces supposed, the arch designed would offer a very great stability.

Similarly if the centre of the ellipse is taken at $\frac{1}{3}$ height of arch above the inverted arch, it will be found that a curve of pressures may be drawn very near the center line, especially if the surcharge has a less specific gravity than the arch. In fact, the ellipse is recognized as the proper form for tunnel arches and any part of the curve may be used that will best subserve the purpose in view—the axis of the tunnel always coinciding with that of the ellipse.

From fig. 16 we see that if a semi-circle is used for the curve of the upper part, that the lower part had best be made vertical on the sides. This form of tunnel arch is quite common in practice and is commended when good material is used.

REMARK.—We can easily prove analytically that the ellipse is the proper form for a tunnel arch, when the depth of surcharge is so great that the thrust of the earth at any part of the arch is practically the same. To take the most general case, let the top surface of the earth be ‖ OY in the adjoining figure. Call the pressure, per unit of inclined plane OY, in a vertical derection, p; the conjugate pressure in a direction ‖ OY, per unit of a vertical plane OA, can be represented, according to the theory of earth pressure, by cp, c being a constant. Let OA$=x$, AB$=y$, OAB$=\theta$, and call the thrust at O in the direction OY, tangent to the rib BOD at O, pT.



This rib, or "linear arch," is not supposed to have any bending moments at any point, so that the thrust at any point is tangent to the rib; otherwise a deformation would ensue, due to the normal component, which is contrary to our supposition of a linear arch. The total vertical pressure on OB is py, the conjugate pressure is cpx. Being uniformly distributed, their lever arms about B are, $\frac{y\sin\theta}{2}$, $\frac{x\sin\theta}{2}$, respectively.

Now if any point, as B, of the arc is to be a point in the line of pressures, we must have, taking moments about B,

$$p\mathrm{T}x\sin\theta=\left(\frac{py^2}{2}+\frac{cpx^2}{2}\right)\sin\theta$$

$$\therefore\ y^2=2\mathrm{T}x-cx^2$$

the equation of an ellipse,

Q.E.D.

The equation of ellipse referred to a diameter and the tangent at its vertex, a and b being the semi conjugate diameters is, $y^2=\frac{b^2}{a^2}(2ax-x^2)$.

Comparing with the above, we have,

$$\mathrm{T}=\frac{b^2}{a},\ c=\frac{cp}{p}=\frac{b^2}{a^2}.$$

Or *the intensities of the conjugate pressures are as the squares of the diameters to which they are parallel.*

If in the eq. above we make, $x=\mathrm{OA}=a$, we find, $y=\mathrm{AB}=b$; whence from the last eq., $\frac{a.\ cp}{b.\ p}=\frac{b}{a}$. Now the thrust at O$=p\mathrm{T}=acp$, whilst that at the ends of the conjugate diameter DB, acting ‖ OX, is bp; hence *these forces are proportional to the diameters to which they are parallel.*

To construct the arch, c and a or b must be given to find the other semi diameter from the eq., $c=b^2\div a^2$.

WHEN THE TOP SURFACE OF EARTH IS LEVEL, OY becomes level and $\theta=90°$. a and b are now the semi axes of the ellipse. From the theory of earth pressure, $\frac{cp}{p}=\tan.^2(45°-\frac{1}{2}\Phi)$ whence, for a tunnel arch,

$$\frac{\text{horizontal semi axis}}{\text{vertical semi axis}}=\frac{b}{a}=\tan.(45°-\tfrac{1}{2}\Phi);$$

Φ being the angle of repose.

Next, make $c=1$ (θ being 90°) and the ellipse becomes a *circle.* At any point of the circle consider the two equal forces p_1 p_1 at right angles and acting on a unit of area of planes ⊥ to them. Their resultant acts normally to the circle, and its intensity is easily found to be p, the intensity of the vertical and horizontal components.

Calling $r=a=b$, the radius of the circle, we have the thrust at O$=p\mathrm{T}=pr$, or *the product of the intensity on a unit of circumference by the radius.* This thrust is the same all around the ring.

The above are the principal deductions given by Rankine for the arches given above. The reader is referred to his Civil Engineer for the "geostatic" and other forms of linear arches.

A SILVER medal has been awarded by the Royal Cornwall Polytechnic Society to West's six-cylinder engine, exhibited by Messrs. Plambeck and Darkin, of Queen Victoria Street, London.

SEWER VENTILATION.

From "The Engineer."

While the attention of house builders and the public is daily directed to the necessity for carefully excluding sewer gas from dwelling-houses by the use of improved traps, and plenty of them, it is to be feared that a very important thing is being wholly lost sight of. We allude to the ventilation of main sewers. In the metropolis this has in a few instances been properly provided for; but in the suburbs of London, at all events, the arrangements employed are of the most crude and unsatisfactory description. In theory, sewers ought not to be ventilated at all; this is to say, they should be hermetically sealed by effective water-traps. The scheme has been tried very fully, and with disastrous results, and no more need be said about it. There is reason to believe that the gases generated in sewers are lighter than the air, as a rule, to which there are certain exceptions to which we shall come presently. Be this as it may, it seems to be certain that when drains are laid on anything like a steep inclination, the sewer gas will rise to the highest point in the drain; and it will, under special atmospheric conditions, then force the seals in any traps not of the best kind, and will rush into and flood the houses. To prevent this, street ventilators are fitted which are simply gratings communicating directly with the main sewer below, and it is assumed that these will suffice to prevent any accumulation of pressure in the sewer, great enough to force a seal of say, 1in. of water. But besides these street gratings, the rain-water stack pipes of all suburban houses, with the exception of a few built under special supervision, communicate directly with the main sewer, and it follows that throughout the length of a street the main sewer is tapped at every 20 feet or 30 feet by house rain-water drains, and that an accumulation of pressure in the sewer is apparently impossible, as the sewer gas can rise freely in the stack pipes to the level of the eaves. This being the case, it is not easy to see what good purpose the street grating ventilator can possibly serve.

In theory these arrangements are by no means defective. The sewer gases are provided with means of escaping freely, and it is apparently impossible that the seal of any fairly well-made trap can be forced; but in practice the system works very badly, and it is because this circumstance seems to have been overlooked by nearly all writers on sanitary subjects that we now call our readers' attention to it. In calm weather, with a steady barometer, all goes well, but a sudden fall in the barometer will at once let loose much gas previously imprisoned in the liquid or semi-liquid contents of the sewer. Next we have rain, which stirs up the said contents, and a very foul-smelling and noxious emanation at once begins to try to issue from the street grating and the open tops of the stack pipes. A stack pipe is very like a chimney in the sense that it may or may not "draw," and it is worse off than a chimney, because the force with which the current of sewer gas rises within it is very feeble unless the weather be warm. The position assumed by the open mouth of the stack pipe, just under the eve, is about the worst possible so far as the performance by the pipe of the functions of a ventilator is concerned. In certain states of the weather, the wind deflected from the rood down the mouth of the pipe, not only stops all upward currents, but creates down currents, and causes a plenum in the main sewer. We have seen this effect so strongly manifested, that in a winter's gale 1 inch water seals in a dwelling-house were broken with ease at every gust of wind. Prudent people will trust their lives to nothing less secure than a 2-inch seal, while three inches are easily to be had, and with these the sewer gas no longer finds its way into the houses through the sinks, &c. But it gets in none the less certainly. At times, while a down draught is going on in one set of stack pipes, a sluggish up-draught may, as a conse-

quence, be taking place in others at the opposite side of the street. The sewer gas is often positively heavier than the air, and, under the conditions just named, overflowing from the stack pipes, it descends to the ground, and then, as there is always an in draught to every inhabited house, for obvious reasons, the sewer gas will find its way into the basement, and render it for the time absolutely uninhabitable. If at such periods the intelligent householder will take the trouble to run the stench to earth, he will find from the evidence supplied by his sense of smell, a layer of sewer gas, probably not more than 1-feet thick, spreading itself along the street and overflowing into areas and down steps, and that this gas is lazily welling up from the street grating ventilators. He will also find the sewer gas descending in streams outside certain of his stack pipes, and he will also find that a gentle breeze is blowing, but that the offensive ventilator and stack pipes are sheltered from it. At such times he may rest assured that at some other point in the sewer there is a direct influx of air caused by a down draught in stack pipes, due in its turn to the breeze. We exaggerate in no wise when we say that hundreds of houses in the suburbs of London are liable at any moment to be flooded in this way with sewer gas from the outside, and this with the most perfect traps known to science indoors.

It will be urged that the remedy consists in cutting off the stack pipes from the main sewer by special traps; that is to say, there ought to be a trap in the pipe which unites all the stack pipes, sinks, and closets with the main sewer. This is right, so far as it goes in theory, but in practice the arrangement is not found to work well. In most cases there is not room for such a trap. We are not dealing now, be it remembered, with what are known to builders as "mansions," but with the houses letting at from £40 to £60 a year, which may be counted by the thousand all round London, east, west, north and south. Such traps, to be efficient, must be so placed that they can be examined from time to time. They must be of good proportions, and they are rather expensive affairs. We happen to know that in many instances where they have been fitted they have had to be removed, because they caused more trouble and nuisance than they were worth. If care were taken to provide 3-inch seals to the sinks and closets of a dwelling-house, with proper ventilating pipes, then would the external trap be wholly unnecessary. But let us suppose that the system were universally adopted; we should then have the main sewer cut off from the stack pipes. Would matters be improved? We much doubt it. The gas would then rise through the street ventilators in greater volumes than ever, and flow over the roadway and into the houses. That these ventilators are dangerous nuisances is known to most sanitary engineers; and various devices, in the shape of charcoal baskets, have been adopted to render them harmless. In many cases these have proved useful, but Sir Joseph Bazalgette at all events has pronounced them worse than useless, and they are not now fitted in London. When a complaint is brought before the local authorities that a street ventilator is caus ing a nuisance, a man is sent with a bucket of disinfectant, which is emptied down the ventilator, and the authorities rejoice that they have done all that is needful for the well-being of the community.

We may be asked, what would we have? Ought street ventilators to be done away, and if so how are drains to be ventilated? To this we reply that some years ago the ventilation of town drains constituted a subject of constant discussion among sanitary engineers, while now hardly anything is said about it. Are we to assume that the difficulties to be encountered are too great to be overcome? We think not, and we write in the hope that the subject will once more receive the attention it really deserves. May we venture to suggest that the best way of ventilating a sewer would consist in taking a lesson from the performance in this connection of stack pipes, and developing the idea in a practical shape? As, for example, let it be made compulsory on every builder to carry up a flue through one of the walls of his house, the top of which flue may be made to assume the form of an ordinary blind chimney cap; this flue should freely communicate at its base with the main sewer, either by means of the common drain from the house, or by means of a subsidiary drain. The best position for the flue would be alongside the kitchen

chimney, from which it would constantly derive heat. The result would be at all times a strong—for a sewer ventilator—upward current through the drain flue, which would discharge the sewer gas through an aperture in its side, where it ought to do no harm—at an elevation, at least, far safer than that to which any stack pipe reaches. The cost of the arrangement would be very trifling, and it could be adapted under every conceivable circumstance. When small houses are built in a group, one or two ventilating flues only would suffice, instead of one for each house. Of course, all street ventilators would be closed up.

ELEMENTS OF THE MATHEMATICAL THEORY OF FLUID MOTION.

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I.

THE following paper contains the mathematical investigation of some of the cases of the motion of incompressible, frictionless fluids. The results obtained are to be considered as applying only to this class of fluids, unless the contrary is expressly stated. The paper is intended to be introductory to a treatise which I hope before long to be able to publish.

In a subject so difficult as Hydrodynamics, there is but little chance for the discovery of hitherto unheard of properties of the quantities dealt with, so, in what follows, the reader will not look for much that is absolutely new in the way of fact, although the arrangement of the work and in many cases the methods employed are my own.

The references to the original sources from which information has been drawn, are given in every case, and I trust that these references, together with the matter contained in this paper, will prove of value to any one interested in the most difficult but beautiful problem of fluid motion.

Of late years, much has appeared in different places upon the subject of Hydrodynamics, but, so far as I am aware, there is no general work either in the English, French or German languages. The aim of this paper and the treatise which will follow will be to combine in one work, all of importance that has been written upon the subject, and so enable the student to forego the immense amount of research necessary in order thoroughly to inform himself upon any one branch of the subject.

The short section which appears upon the theory of the Potential, is principally taken from Clausius's work upon that subject. The references to theoretical mechanics are, unless otherwise stated, to Thomson and Tait's Natural Philosophy. Kirchhoff's Mathematische Physik and Clifford's Elements of Dynamic, have also been consulted.

§ I.

GENERAL EQUATIONS OF FLUID MOTION.

Let X, Y, Z denote as usual the component forces acting at the point (x, y, z) of the fluid reckoned per unit of its mass —then denoting by ρ the density of the fluid we have for the forces acting upon the elementary mass $\rho dadydz$ the expressions

$$X\rho dxdydz,\ Y\rho dxdydz,\ Z\rho dxdydz;$$

Now for the fluid pressure acting upon one face of the elementary parallelopiped, say, $\delta y\delta z$ we have $p\ \delta y\delta z$, p denoting the pressure on unit of area; upon the opposite face it is, neglecting powers of dx higher than the first,

$$-\delta y\delta z\left(p+\frac{dp}{dx}\delta x\right)$$

Consequently the resultant force due to fluid pressure acting in the direction of the axis x is,

$$-\delta y\delta z\frac{dp}{dx}\delta x.$$

The equilibrium of this portion of the fluid therefore requires that

$$\delta x\delta y\delta z\frac{dp}{dx}-\rho X\delta x\delta y\delta z=o$$

with similar expressions for the other pairs of faces. We have thus for the equations of fluid equilibrium,

$$\frac{dp}{dx}=\rho X$$

$$\frac{dp}{dy}=\rho Y$$

$$\frac{dp}{dz}=\rho Z$$

These three equations can, of course, be replaced by the single equation of equilibrium.

$$dp=\rho(Xdx+Ydy+Zdz)$$

when dp denotes the variation of pressure corresponding to the changes dx, dy, dz, in the co-ordinates of the point at which the pressure is estimated. We see from this equation that the expression,

$$Xdx+Ydy+Zdz,$$

is either an exact differential or capable of being made so by a factor. If the forces X, Y, Z belong to a conservative system, that is, a system possessing a potential, or for which the absent expression is an exact differential, we know that

$$\frac{dX}{dy}-\frac{dY}{dx}=o \text{ \&c.}$$

But when these conditions are satisfied the quantity $Xdx+Ydy+Zdz$ is an exact differential, or in the case of a system of conservative forces we have without the assistance of any interpreting factor

$$Xdx+Ydy+Zdz=d\mathrm{R}$$

when R is the potential of the forces at the point (x,y,z). It follows from this that $dp=-\rho\mathrm{R}$, or that p is a function of R, then for all surfaces for which R is constant p is also constant, *i.e.* the pressure is constant over all equi-potential surfaces. From these equations of equilibrium we can pass directly to the equations of motion, by means of D'Alembert's principle. Call u, v, w, the velocities of a particle of the fluid whose co-ordinates at the time t are x,y,z, thus,

$$u=\frac{dx}{dt},\ v=\frac{dy}{dt},\ w=\frac{dz}{dt};$$

let u', v', w', denote the accelerations to which these velocities give rise, then in our equations of equilibrium replacing X, Y, Z by,

$$X-u',\ Y-v',\ Z-w'$$

we have for the equations of motion

$$\frac{dp}{dx}=\rho(X-u'),$$

$$\frac{dp}{dy}=\rho(Y-v'),$$

$$\frac{dp}{xz}=\rho(Z-w')$$

when we have of course,

$$u'=\frac{du}{dt}+\frac{du}{dx}\frac{dx}{dt}+\frac{du}{dy}\frac{dy}{dt}+\frac{du}{dz}\frac{dz}{dt}$$

$$=\left(\frac{d}{dt}+u\frac{d}{dx}+v\frac{d}{dy}+w\frac{d}{dz}\right)u.$$

We may for brevity replace this operator by $\frac{\mathrm{D}}{\mathrm{D}t}$, and we have thus for the equations of fluid motion the following:

$$\frac{dp}{dx}=\rho\left(X-\frac{\mathrm{D}u}{\mathrm{D}t}\right),$$

$$\frac{dp}{dy}=\rho\left(Y-\frac{\mathrm{D}v}{\mathrm{D}t}\right),$$

$$\frac{dp}{dz}=\rho\left(Z-\frac{\mathrm{D}w}{\mathrm{D}t}\right).$$

Concerning the operator which we have denoted by $\frac{\mathrm{D}}{\mathrm{D}t}$, it is important to observe that it relates to a particular particle and not to a particular point in space; the velocities u, v, w, are functions of x, y, z and t, and denote the velocity which *any* particle has when it occupies the position denoted by x, y, z *and* $\frac{du}{dt}$ dt denotes the increase of velocity of a second particle over the one originally in this position, which arrives at this point after the lapse of time dt, while on the other hand, $\frac{\mathrm{D}u}{\mathrm{D}t}dt$ denotes the change in velocity of the original particle during this time. When the motion is very small, the terms $u\frac{d}{dx}$, &c. may be neglected, and we would have,

$$\frac{D}{Dt}=\frac{d}{dt}$$

To our equations of motion it is necessary to add one more, expressing the continuity of the fluid. This equation simply expresses the fact, that during any natural motion there can be neither annihilation or germination of matter, or, referring to our problem, that the amount of fluid in any space at any time must be equal to the amount originally contained in that space, increased by the amount which has entered it during the time which has been allowed to pass, diminished by the amount which has left it during that time.

Let a, b, c, denote the co-ordinates of any particle of the fluid at an initial instant, x, y, z, denote the values of these co-ordinates at the time t; now in order completely to specify the motion it is necessary to express these latter quantities as functions of initial co-ordinates and the time. Suppose further, that δa, δb, δc, are the edges of a small parallelopiped of the fluid, as these are assumed to be infinetisimal, the figure will remain a parallelopiped during the motion.

We have now for the co-ordinates of the extremities of the edges meeting in the point a, b c,

$$a+\delta a,\ b,\ c,\quad a,\ b+\delta b,\ c,\quad a,\ b,\ c+\delta c$$

at the time t the co-ordinates of these points will be,

$$\begin{array}{ccc} x, & y, & z, \\ x+\dfrac{dx}{da}\delta a, & y+\dfrac{dy}{da}\delta a, & z+\dfrac{dz}{da}\delta a \\ \vdots & \vdots & \vdots \end{array}$$

From these we arrive, by a smple geometrical process, at the volume of the parallelopiped, which is then at the time t.

$$\begin{vmatrix} \dfrac{dx}{da}, & \dfrac{dy}{da}, & \dfrac{dz}{da} \\ \dfrac{dx}{db}, & \dfrac{dy}{db}, & \dfrac{dz}{db} \\ \dfrac{dx}{dc}, & \dfrac{dy}{dc}, & \dfrac{dz}{dc} \end{vmatrix} \delta a\delta b\delta c$$

or representing the determinant by Δ, $\Delta\,\delta a\delta b\delta c$; hence by our definition of continuity we must have

$$\Delta=1,$$

or in general if ρ_0 and ρ denote the initial and final densities of the fluid contained in this portion of space

$$\rho\Delta=\rho_0$$

which simply expresses the fact that the density of the fluid contained in this portion of space must vary inversely as the volume of the space.

This equation is known as the integral equation of continuity. The form of the equation most generally employed, however, is that which expresses the fact that the rate of diminution of density bears to the density at any instant the same ratio that the rate of increase of the volume of an infinitely small portion of the fluid bears to the same infinitely small volume at the same instant. The symbolical expression of this fact constitutes the *differential equation of continuity* of the fluid.

Let the flow towards the inside of an elementary parallelopiped of the fluid be considered as positive, then the flow towards the outside will be negative. Representing as before the edges of this elementary parallelopiped by δx, δy, δz we have for the flow through the face $\delta y\ \delta z$ in the direction of x and during the time dt

$$\rho\delta y\delta z u dt$$

through the opposite face the flow will be during the same time

$$-\delta y\,\delta z\left(\rho u+\frac{d\rho u}{dx}.\delta x\right)dt.$$

These together give rise to an increase of mass

$$-\delta x\delta y\delta z\frac{d\rho u}{dx}dt$$

with similar expressions for the other pairs of faces respectively, perpendicular to the axis of y and z. Then the total increase of mass is

$$-\delta x\delta y\delta z\left(\frac{d.\rho u}{dx}+\frac{d.\rho v}{dy}+\frac{d.\rho w}{dz}\right);$$

but this increase of mass is also given by

$$\delta x\delta y\delta z\frac{d\rho}{dt}dt;$$

equating these values and we have for the equation of continuity

$$\frac{d\rho}{dt}+\frac{d.\rho u}{dx}+\frac{d.\rho v}{dy}+\frac{d.\rho w}{dz}=o$$

or for incompressible fluids simply,

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=o$$

It may not be uninteresting to show how this differential equation of continuity can be derived from the integral equation. We have, denoting the mass of this elementary portion of fluid by m,

$$m=\rho\begin{vmatrix} \frac{dx}{da}, & \frac{dx}{db}, & \frac{dx}{dc} \\ \frac{dy}{da}, & \frac{dy}{db}, & \frac{dy}{dc} \\ \frac{dz}{\delta a}, & \frac{dz}{\delta b}, & \frac{dz}{\delta c} \end{vmatrix}\delta a\ \delta b\ \delta c$$

Differentiating this with respect to t we have

$$o=\triangle\frac{\mathrm{D}\rho}{\mathrm{D}t}+\rho\frac{d\triangle}{dt}$$

or

$$o=\frac{\mathrm{D}\rho}{\mathrm{D}t}+\frac{\rho}{\triangle}\cdot\frac{d\triangle}{dt}$$

the quantity $\frac{1}{\triangle}\frac{d\triangle}{dt}$ will be found by easy reductions to be equal to

$$\frac{du}{dx}+\frac{dv}{dy}\frac{dw}{dz}$$

and the equation thus becomes

$$o=\frac{\mathrm{D}\rho}{\mathrm{D}t}+\rho\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)$$

from which we obviously obtain the forms given above. Particular forms of this equation for special cases are often quite simple—as, for example—suppose the motion of the fluid to be wholly parallel to the plane xy; in this case we have simply

$$\frac{du}{dx}+\frac{dv}{dy}=o$$

but $\frac{du}{dx}=-\frac{dv}{dy}$ is the condition that the expression

$$udy-vdx$$

be an exact differential; calling it $d\Psi$ we have

$$u=\frac{d\Psi}{dy},\quad v=-\frac{d\Psi}{dx}.$$

The quantity Ψ is called the stream function, and all motion takes place in the direction of the curves $\Psi=$const.

If the motion be steady, the lines $\Psi=$const. will form a system of tubes in the fluid, which may be called the tubes of flow. A much more general simplification of the equations of hydrodynamics exists however for certain classes of motion. It is a fact, the discovery of which is due to Lagrange that if at any time the expression

$$udx+vdy+wdz$$

is an exact differential, it will remain so throughout the motion; that is, if at any time we have

$$\frac{du}{dx}-\frac{dv}{dy},\ \frac{dw}{dx}-\frac{du}{dz},\ \frac{du}{dy}-\frac{dv}{dx},\ =o$$

these quantities will remain so throughout the motion. Representing these quantities by ξ, η, δ, we may express this fact in another manner, viz. if at any time the motion of the fluid be irrotational, it will remain so during the entire motion. In particular, if the fluid originally at rest be set in motion, by a system of conservative forces or pressures, there will be no motion of rotation throughout the entire motion. The following proof of this theorem is that given by Sir Wm. Thomson in his paper on "Vortex Motion," Edin. Trans. 1869. As this proof does not depend upon the quantity ρ, we can give it in general representing by ω the integral $\int\frac{dp}{\rho}$. We have then from our equations of motion

$$d\pi=\mathrm{X}dx+\mathrm{Y}dy+\mathrm{Z}dz-\left(\frac{\mathrm{D}u}{\mathrm{D}t}dx+\frac{\mathrm{D}v}{\mathrm{D}t}dy+\frac{\mathrm{D}w}{\mathrm{D}t}dz\right)$$

Now, according to hypothesis,

$$\mathrm{X}dx+\mathrm{Y}dy+\mathrm{Z}dz=d\mathrm{R},$$

and obviously,

$$\frac{\mathrm{D}u}{\mathrm{D}t}dx+\frac{\mathrm{D}v}{\mathrm{D}t}dy+\frac{\mathrm{D}w}{\mathrm{D}t}dz=\frac{\mathrm{D}}{\mathrm{D}t}(udx+vdy+wdz)-\left(u\frac{\mathrm{D}dx}{\mathrm{D}t}+v\frac{\mathrm{D}dy}{\mathrm{D}t}+w\frac{\mathrm{D}dz}{\mathrm{D}t}\right)$$

or since

$$\frac{\mathrm{D}dx}{\mathrm{D}t}=\frac{d\mathrm{D}x}{\mathrm{D}t}=u,\ \&c.$$

$$d\pi = d\mathrm{R} - \frac{\mathrm{D}}{\mathrm{D}t}(udx+vdy+wdz) + (udu+vdv+wdw)$$

or representing $u^2+v^2+w^2$ by V^2,

$$\frac{\mathrm{D}}{\mathrm{D}t}udx+vdy+wdz) = d(\mathrm{R}+\tfrac{1}{2}\mathrm{V}^2-\pi).$$

Integrating this along any arc (12) moving with the fluid we have

$$\frac{\mathrm{D}}{\mathrm{D}t}\int(udx+vdy+wdz) = (\mathrm{R}+\tfrac{1}{2}\mathrm{V}^2-\pi)_1 - (\mathrm{R}+\tfrac{1}{2}\mathrm{V}^2-\pi).$$

If the arc be a closed circuit the second member of this equation vanishes and we have

$$\frac{\mathrm{D}}{\mathrm{D}t}\int(udx+vdy+wdz) = o,$$

or this may be expressed by saying that *the line integral of the tangential component velocity around any closed curve of a moving fluid remains constant throughout all time.* The line integral is called the *circulation*, and the proposition may be stated. *The circulation in any closed line moving with the fluid remains constant.* In a state of rest the circulation is, of course, zero; therefore, for the assumed case of motion generated by pressures or conservative forces we have that the circulation is always zero, so that $udx+vdy+wdz$ is an exact differential. Representing this quantity by $d\varphi$ we have

$$u = \frac{d\varphi}{dx}, v = \frac{d\varphi}{dy}, w = \frac{d\varphi}{dz}$$

from which we have for the differential equation of continuity

$$\frac{d^2\varphi}{dx^2} + \frac{d^2\varphi}{dy^2} + \frac{d^2\varphi}{dz^2} = o$$

or simply

$$\Delta^2\varphi = o.$$

The quantity φ is appropriately called the velocity function, and the velocity in *any* direction is expressed by the corresponding rate of change of φ. We may just here observe one fact concerning φ. If φ is a minimum at any point, *i.e.* if it increases as we go away from that point there must evidently be a positive expansion of the fluid from this point in all directions. Similarly if φ be a maximum at any point. Then the motion is in all directions towards this point and there is compression of the fluid.

If there be neither expansion nor compression of the fluid within the region bounded by a closed surface, the greatest and least values of the velocity potential in that region must be on the surface; for since there is no expansion or contraction, there can be no maximum or minimum value within this surface. If, therefore, the velocity potential is constant over the surface, it must be constant throughout the enclosed region, since its greatest and least values are now equal. In particular, if it is zero over the surface, it must be zero throughout the enclosed region. When the velocity potential exists, the equation for determining the pressure can be put into a very simple form, viz.

$$d\pi = d\mathrm{R} - \frac{\mathrm{D}}{\mathrm{D}t}d\varphi + \tfrac{1}{2}d\mathrm{V}^2$$

integrating

$$\pi = \int\frac{dp}{\rho} = \mathrm{R} - \frac{\mathrm{D}\varphi}{\mathrm{D}t} + \tfrac{1}{2}\mathrm{V}^2$$

but

$$\frac{\mathrm{D}\varphi}{\mathrm{D}t} = \frac{d\varphi}{dt} + u^2 + v^2 + w^2 = \frac{d\varphi}{dt} + \mathrm{V}^2$$

so that

$$\pi = \int\frac{dp}{\rho} = \mathrm{R} - \left(\frac{d\varphi}{dt} + \tfrac{1}{2}\mathrm{V}^2\right)$$

or for our assumed case of incompressible fluids

$$\frac{p}{\rho} = \mathrm{R} - \left(\frac{d\varphi}{dt} + \tfrac{1}{2}\mathrm{V}^2\right)$$

Another form of the equations of fluid motion due to Lagrange is worthy of notice here, though the forms already given, or Euler's equations, are those employed in general in hydrodynamics. Since the quantities a, y, 2, are functions of the initial coördinates of the point, we have

$$\frac{dp}{da} = \frac{dp}{dx}\frac{dx}{da} + \frac{dp}{dy}\frac{dy}{da} + \frac{dp}{dz}\frac{dz}{da}$$
$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

from these we have

$$\frac{dp}{dx} = \frac{1}{\Delta}\begin{vmatrix} \frac{dp}{da}, & \frac{dy}{da}, & \frac{dz}{da} \\ \frac{dp}{db}, & \frac{dy}{db}, & \frac{dz}{db} \\ \frac{dp}{dc}, & \frac{dy}{dc}, & \frac{dz}{dc} \end{vmatrix} \quad \&c.$$

but we have also

$$\frac{1}{\rho}\frac{dp}{dx}=X-\frac{d^2x}{dt^2}\&c.$$

Substituting the values of $\frac{dp}{dx}$ from these last equations in those giving the values of $\frac{dp}{da}$—and we have the Lagrangean equations of fluid motion, viz.

$$\left\{\frac{d^2x}{dt^2}-X\right\}\frac{dx}{da}+\left\{\frac{d^2y}{dt^2}-Y\right\}\frac{dy}{dx}+\left\{\frac{d^2z}{dt^2}-Z\right\}\frac{dz}{da}+\frac{1}{\rho}\frac{dp}{da}=o$$

with two similar ones containing b and c, respectively. The reader can see that from these equations we can readily pass to the forms given before. Where the forces X, Y, Z have a potential and there is also a velocity potential, these equations become

$$\frac{d^2x}{dt^2}\frac{dx}{da}+\frac{d^2y}{dt^2}+\frac{dy}{da}\frac{d^2z}{dt^2}\frac{dz}{da}=\frac{d(R-\pi)}{da}$$

$$\frac{d^2x}{dt^2}\frac{dx}{db}+\frac{d^2y}{dt^2}\frac{dy}{db}+\frac{d^2z}{dt^2}\frac{dz}{db}=\frac{d(R-\pi}{db}$$

$$\frac{d^2x}{dt}\frac{dx}{dc}+\frac{d^2y}{dt^2}\frac{dy}{dc}+\frac{d^2z}{dt^2}\frac{dz}{dc}=\frac{d(R_1-\pi)}{dc}$$

Differentiate the second of these equations with respect to c, the third with respect to b, and subtract the latter result from the former. It will be sufficient to examine only two terms of the result; we have then

$$\frac{d}{dc}\left\{\frac{d^2x}{dt^2}\frac{dx}{db}\right\}-\frac{d}{db}\left\{\frac{d^2x}{dt^2}\frac{dx}{dc}\right\}=\frac{dx}{db}\frac{d^2}{dt^2}\frac{dx}{dc}-\frac{dx}{dc}\frac{d^2}{dt^2}\frac{dx}{db}$$

$$=\frac{d}{dt}\left\{\frac{dx}{db}\frac{d}{dt}\frac{dx}{dc}-\frac{dx}{dc}\frac{d}{dt}\frac{dx}{db}\right\}=\frac{d}{dt}\left\{\frac{dx}{db}\frac{du}{dc}-\frac{dx}{dc}\frac{du}{db}\right\}\&c.,$$

the remaining terms will be obtained by advancing the letters. We have then a quantity which differentiated for t is $=0$. Performing similar operations on the remaing pairs of equations we arrive readily at the following equations, where C_1, C_2, C_3 denote quantities which are independent of the time.

$$\left\{\frac{dx}{da}\frac{du}{db}-\frac{dx}{db}\frac{du}{da}\right\}+\left\{\frac{dy}{da}\frac{dv}{db}-\frac{dy}{db}\frac{dv}{da}\right\}+\left\{\frac{dz}{da}\frac{dw}{db}-\frac{dz}{db}\frac{dw}{da}\right\}=C_1$$

$$\left\{\frac{dx}{dc}\frac{du}{da}-\frac{dx}{da}\frac{du}{dc}\right\}+\left\{\frac{dy}{dc}\frac{dv}{da}-\frac{dy}{da}\frac{dv}{dc}\right\}+\left\{\frac{dz}{dc}\frac{dw}{da}-\frac{dz}{da}\frac{dw}{dc}\right\}=C_2,$$

$$\left\{\frac{dx}{db}\frac{du}{dc}-\frac{dx}{dc}\frac{du}{db}\right\}+\left\{\frac{dy}{db}\frac{du}{dc}-\frac{dy}{dc}\frac{du}{db}\right\}+\left\{\frac{dz}{db}\frac{dw}{dc}-\frac{dz}{dc}\frac{dw}{db}\right\}=C_3.$$

Let now u_0, v_0, w_0 represent the values of u, v, w for $t=o$, thus at this time we have

$$u=u_0,\ v=v_0,\ w=w_0$$
$$x=a,\ y=b,\ z=c;$$

Substituting these values in the above equations and they reduce immediately to

$$\frac{du_0}{db}-\frac{dv_0}{da}=C_1$$
$$\frac{dw_0}{da}-\frac{du_0}{dc}=C_2$$
$$\frac{dv_0}{dc}-\frac{dw_0}{db}=C_3$$

We have further, since u, v, w are functions of x, y, z,

$$\frac{du}{da}=\frac{du}{dx}\frac{dx}{da}+\frac{du}{dy}\frac{dy}{da}+\frac{du}{dz}\frac{dz}{da}\&c.$$

If now in our determinant Δ we denote the separate minors by A_1, B_1, Γ_1, and Γ_2, *i. e.*,

$$A_1=\frac{dy}{db}\frac{dz}{dc}-\frac{dy}{dc}\frac{dz}{da}\&c.$$

substituting now the values of $\frac{du}{da}$ &c. in the above equations C_1, C_2, C_3 and noting these last abreviations we have, since for incompressible fluids $\Delta=1$,

$$A_1\left\{\frac{dv}{dz}-\frac{dw}{dy}\right\}+B_1\left\{\frac{dw}{dx}-\frac{du}{dz}\right\}+\Gamma_1\left\{\frac{du}{dy}-\frac{dv}{dz}\right\}=\frac{dv_0}{dc}-\frac{dw_0}{db}$$

$$A_2\left\{\frac{dv}{dz}-\frac{dw}{dy}\right\}+B_2\left\{\frac{dw}{dx}-\frac{du}{dz}\right\}+\Gamma_2\left\{\frac{du}{dy}-\frac{dv}{dz}\right\}=\frac{dw_0}{da}-\frac{du_0}{dc}$$

$$A_0\left\{\frac{dv}{dz}-\frac{dw}{dy}\right\}+B_0\left\{\frac{dw}{dx}-\frac{du}{dz}\right\}+\Gamma_0\left\{\frac{du}{dy}-\frac{dv}{dz}\right\}=\frac{du_0}{db}-\frac{dv_0}{da}$$

Representing the quantities on the right hand side, as we appropriately may, by $2\xi_0$, $2\Gamma_0$, $2\delta_0$, and solving the equations for the quantities within the parenthesis, we have

$$\xi=\xi_0\frac{dx}{da}+\eta_0\frac{dx}{db}+\delta_0\frac{dx}{dc}$$

$$\eta=\xi_0\frac{dy}{da}+\eta_0\frac{dy}{db}+\delta_0\frac{dy}{db}$$

$$\delta=\xi_0\frac{dz}{da}+\eta_0\frac{db}{dz}+\delta_0\frac{dz}{dc}$$

If the quantities ξ_0, Γ_0, δ_0, which are the initial angular velocities of the particle of the fluid whose co-ordinates at $t=o$ a, b, c, are $=o$, we have that ξ, Γ, δ must also be $=o$, that is, we arrive again at the theorem that if there be no original motion of rotation in the fluid there will be none at any future time. It will be of interest to obtain the equations which were used by Helmholtz in his great memoir on vortex motion. These are simply obtained from our equations of motion. The first of these equations written out in full is

$$\frac{dw}{dx}=X-\frac{du}{dt}-u\frac{du}{dx}-v\frac{du}{dy}-w\frac{du}{dz}\ \&c.$$

Now supposing the fluid initially at rest to be set in motion by conservative forces and pressures from the exterior, the analytic conditions for this are

$$\frac{dX}{dy}-\frac{dY}{dx}=o\ \&c.$$

Therefore differentiating the first equation with respect to y and the second with respect to x, and subtracting we eliminate ω and the impressed forces, and have

$$o=\frac{d}{dx'}\frac{dv}{dt}-\frac{d}{dy}\frac{du}{dt}+\frac{du}{dx}\left\{\frac{dv}{dx}-\frac{du}{dy}\right\}+\left\{u\frac{d}{dy}\frac{dv}{dx}-u\frac{d}{dx}\frac{du}{dx}\right\}+..$$

from this we have obviously

$$\frac{D\delta}{Dt}=\frac{du}{dz}\xi+\frac{dv}{dz}\eta-\left\{\frac{du}{dx}+\frac{dv}{dy}\right\}\delta$$

and remembering that for incompressible fluids we have

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=o$$

this becomes

$$\frac{D\delta}{Dt}=\frac{du}{dz}\xi+\frac{dv}{dz}\eta+\frac{dw}{dz}\delta$$

And similarly

$$\frac{D\xi}{Dt}=\frac{du}{dx}\xi+\frac{dv}{dx}\eta+\frac{dw}{dx}\delta,$$

$$\frac{D\eta}{Dt}=\frac{du}{dy}\xi+\frac{dv}{dy}\eta+\frac{dw}{dy}\delta.$$

The principle of the persistence of initially irrotational motion obviously follows from these equations.

ON THE FRICTIONAL RESISTANCES OF PNEUMATIC FOUNDATIONS.

By A. SCHMOLL.

From "Zeitschrift des Vereines Deutscher Ingenieure," Abstracts published by the Institution of Civil Engineers.

In applying pneumatic foundations for bridge piers it is important to know the amount of fractional resistance encountered by caissons in various strata and at different depths, in order to determine the load necessary to overcome this resistance, or in case of light, insufficiently resisting soil, to determine the depth to which a pier must be sunk to carry the load.

Cast-iron cylinders or caissons with casements, can be detached from the chains by which they have been kept in position, as soon as the columns have well penetrated the ground, whereby the sinking proceeds quicker, and the quantity of loose earth, forced under the lower edge of the caisson into the excavating chamber, is considerably reduced. For the erection of four cylinders of the Kehl bridge over the Rhine, where no cofferdams were used, the quantity of sand and stone removed from the interior of the excavating chamber was about

21,000 cubic yards, while the space occupied by the subterranean portion of the cylinders was only 13,734 cubic yards, the difference arising from the influx of loose earth and sand into the excavations.

According to the experience of the author, not only the nature of the soil but also the shape of the column influences the frictional resistance, the latter being smaller for cast-iron cylinders and rectangular caissons than for caissons of an oblong section.

The details given relate to the application of cast-iron cylinders, or of wrought-iron riveted caissons with vertical sides and with casings reaching above the water level for strata which form the bed of the Seine, Rhine, and Danube. In determining the frictional resistance the following conditions must be observed:

1. The tube or caisson must be vertical.

2. It must be free on all sides, neither attached to the guide chains nor resting upon its lower edge, but only kept in equilibrium by its weight, by the friction on its circumference and by the internal air pressure.

To achieve these conditions the total weight of the cylinder must be less than the frictional resistance, plus the weight of the displaced water; or else sinking takes place without air being let off, and without the cutting edge being undermined. If these conditions be fulfilled, the air pressure shown by a gauge is recorded, the safety valve opened, and after the sinking motion of the caisson has begun, the air pressure is again observed and the valve rapidly closed. The beginning of the motion indicates that the effective air pressure, together with the friction at the circumference of the caisson, have become slightly smaller than the cylinder.

EXPERIMENTS ON CO-EFFICIENTS OF FRICTION.

As co-efficients of friction relating to materials and surfaces which occur in pneumatic foundations were unknown to the author, he determined the following by direct experiments made in March, 1876, in Vienna, with the aid of a dynamometer.

Description of Materials.	Co-efficients of Friction.			
	At the Beginning of Motion.	During the Motion.	Beginning of Motion.	During Motion.
	For Dry Materials.		For Wet Materials.	
Sheet iron without rivets on gravel mixed with sand.	0.4015	0.4583	0.3348	0.4409
Sheet iron with rivets on gravel and sand.....	0.3965	0.4911	0.4677	0.5481
Cast iron (unplaned) " "	0.3677	0.4668	0.3646	0.4963
Granite (roughly worked) " "	0.4266	0.5368	0.4104	0.4800
Pine (sawn) " "	0.4088	0.5109	0.4106	0.4985
Sheet iron without rivets on sand.....	0.5361	0.6313	0.3655	0 3247
" with " "	0.7269	0.8391	0.5156	0.4977
Cast iron (unplaned) " "	0.5636	0.6063	0.4744	0.3796
Granite (roughly worked) "	0.6473	0.7000	0.4728	0.5291
Pine (sawn) "	0.6633	0.7340	0.5787	0.4793

Each figure is the average result of at least ten experiments. Between two consecutive experiments there was an interval of from eight to ten minutes. All materials were rounded off at their face in sledge shape and drawn lengthwise and horizontally over the gravel or sand; the latter was well levelled and bedded as solid as it is likely to be in its natural position. The riveted sheet iron contained twenty-five rivets on a surface of $2.53 \times 1.67 = 4.22$ square feet, the rivet heads were half round and of $\frac{3}{16}$ inch diameter.

Contrary to the experience of General Morin with other materials, it follows from these experiments, that for the above-named rough materials, the resistance of friction from rest is smaller than the resistance during the motion.

As the author's experiments relate to materials with rough surfaces this remarkable fact can be explained by the supposition that during the motion the small cavities and depressions on the sheet iron, cast-iron, wood, and stone surfaces become filled with dry sand which adheres to the surface, so that the effect is nearly the same as though two surfaces of dry sand were in contact with each other.

But for the friction of the surfaces of the same materials (except granite) on wet sand the reverse occurs. The friction during the motion is smaller than the friction at the beginning of motion. Probably the wet sand forms a more solid bed for the wet bodies sliding over it, in consequence of which the small depressions of the latter are not filled with sand so easily as in the case of dry surfaces.

CALCULATION OF THE RESISTANCE OF FRICTION IN PNEUMATIC FOUNDATIONS.

First example: Experiments made on the 2d of June, 1863, with the upper part of column V of the railway viaduct over the Seine at Orival near Elbœuf. As soon as the cast-iron cylinder, standing in an extensive and rather uniform bed of gravel, and having ceased to move for thirty-two hours, completely fulfilled all conditions necessary for such an experiment, and was undermined about 6 inches, the workmen left the column and the safety-valve was opened. When the air pressure had sunk from 1.20 to 1 atmosphere above the normal pressure of the atmosphere, the cylinder began to move, and at once sank 13 inches. It would have sunk deeper if the experimenter had not arrested the escape of air by closing the safety-valve at the beginning of the motion. At the moment of sinking the water had risen in the lower ring to a height of 34 inches.

Some minutes after this first experiment a second and third was made with the same cylinder, when it sank 13 inches and 12.6 inches respectively, the total fall for the three consecutive experiments therefore being 38½ inches.

The weight of the column, including iron, concrete, masonry, and woodwork, was 218 tons.

The loss of weight by immersion at the moment when friction was overcome and the column began to sink was

$$[(10.20 \times 10.1788) + (1.00 \times 10.3491) - (0.87 \times 9.7868)] \times 1000 = 105{,}659$$

kilogrammes (104 tons).

10.20 metres being the height of the immersed part of the column including the lowest ring, and 10.1788 square metres the superficial area of the cylinder (diameter = 3.6 metres, and circumference = 11.31).

Metre.

1.00 = height } of the lowst
10.3491 = superficial area } ring.

9.87 = height of inner water level over the cutting edge.

9.7868 = superficial area of water in the lowest ring.

The resistance of friction was therefore:

$$222{,}231 - 105{,}659 = 116{,}572$$ kilogrammes (114 tons).

The author further cites (Example 2) an experiment with the first caisson of the right abutment of the railway bridge over the Danube between Vienna and Stadlau (Austrian State Railway), 5th of November, 1868, the results being nearly the same as in No. 1.

It sometimes occurs that, when the cylinder is in clay soil, the water does not enter into the working chamber, although the compressed air may have been completely left out. This was the case in experiments made by the author during the sinking of the cylinder mentioned in Example No. 2, on the 31st of December, 1868, and on the 2d and 4th of January, 1869. If the sinking of the caisson, in consequence of a decrease of the pressure of the air in the interior has begun, and the water fails to enter into the working chamber, the loss of weight by immersion is determined in two ways, first, by multiplying the air pressure per unit remaining in the interior of the caisson, with the base of the caisson; and second, in assuming that the water column replaced by the sinking object, has only a height equal to the vertical distance of the surface of the clay from the external water level.

Of the two calculated results the larger one is considered to be the buoyancy or loss of weight of the immersed object,

and to be deducted from the total weight of the latter, the difference being the resistance of friction.

The third example cited is an experiment made with No. 1 column (right bank) of the bridge over the Danube near Stadlau, on the 4th of January, 1869. The total weight of the sinking column was 1,305 tons. The cylinder began to sink when the air pressure had fallen from 1 atmosphere to 0.85 atmosphere, and in consequence of a further escape of air it gradually sank in one minute 18½ inches. The caisson being in a layer of solid clay of 3.73 feet thickness before it began to move, the water failed to enter into the cylinder.

The weight of the displaced water column, taking its height 27.35 feet, was 594 tons, and the upper pressure of the compressed air inside the cylinder was 625 tons. Deducting the latter result from the total weight of the caisson the frictional resistance on the surface of the cylinder is 678 tons. The column was sunk into the soil to a depth of 18.76 feet.

If the water fails to enter into the working chamber after a complete escape of the compressed air, the upward pressure is represented by the weight of the displaced water, taking as its height the vertical distance of the external water level from the water-tight soil, and the amount of frictional resistance is obtained by deducting this pressure from the total weight of the object.

The examples from which the author obtained his results are recorded in a series of tables, which show clearly that, in homogeneous strata, the resistance per unit of frictional surface decreases with the increasing depth. From this it is to be concluded that the density and cohesion of these strata augment with increasing depth, and therefore the pressure upon the sides of the column becomes less than in the upper strata.

MATTERS AFFECTING THE USE OF STEEL.

By M. ERNEST MARCHE.

Read before the Iron and Steel Institute at Paris.

(1.) The manufacture of commercial steel produced by the Bessemer and Martin-Siemens processes, and of cognate articles, has been greatly developed of late, more especially during the last ten years, on account of the demand, on the part of railway companies, for steel rails, axles and tires, and, on the part of the navy, for sheet plates and profile thwarts, &c. This rapid increase in the demand for steel is the result of the reduction of the price of manufacture, and that reduction is attributable to improved processes, as well as to the augmented power of the apparatuses employed; but, even under these circumstances, so speedy a development would not have been obtained had not metallurgists succeeded in producing, at will and regularly, steel of a different but well-defined nature, and had not their customers attained, by means of methodical experiments, to a gradually complete knowledge of the physical properties of, and the mode of employing, each of the steel productions in question. Whilst the chemical analysis constituted the indispensable guide for the choice of the raw materials, as well as for the study of the various processes, the experiments in respect of the elasticity, malleability and power of resistance of the manufactured pieces could alone impart confidence to the parties making use of the articles, and enable them to extend the sphere of reasonable applications of commercial steels. The laboratory of the chemist, and the machinery employed in the experiments, were of equal utility to the metallurgist and the engineer.

(2.) The researches as to the physical properties of the steels were undertaken in three different points of view. Very numerous and beautiful experiments, of an eminently scientific character, were required from the adepts in natural philosophy, and from learned men, and they on their part operating with powerful apparatuses, and availing themselves of the most improved processes, whilst making thorough and minute observations of

all phenomena, as well as of the strains and the deformations, have been enabled to lay before the public very valuable documents, treating, as a whole, of the properties of steel. It is to that class of operations that we are indebted for the works of Mr. D. Kirkaldy, Mr. Knut Styffe, Colonel Bosat, Professor Bauschinger, &c. In some ironworks, too, their productions were subjected to a serious examination, limited, however, to the determination of certain characteristic properties (as compared with the chemical composition) of the process of manufacture, the degree of elaboration, &c. Those experiments led to the classification of those works, as exercising a great influence on the extension of industrial applications, for example, the Creusot, Neuberg, J. Cotterill, Terre Noire, and other works—a classification bearing, for example, on the question as to the quantity of carbon contained, or to the resisting power, and the elongations in regard to traction. Finally, railway board contractors and military and naval authorities have prescribed a series of different tests for the articles ordered by them, according to the form and destination of these articles, and the reports that have appeared supply elements for the careful study of the practical results in a commercial point of view. The Universal Exhibition of 1878 has already served to enrich the already valuable collection of the triple series of experiments already referred to, by enumerating those that have been made in regard of Swedish plates, by the Jernkontoret (Swedish Iron Association); those on the castings, irons and steels of the Reschitza Works (Hungary), undertaken by Professor Bauschinger, and the experiments, mentioned in the Exhibition Catalogue, of the Terre Noire, La Voulte and Besiges Foundries and Ironworks, as well as the results of the experiments conducted on some classes of steel, with variable ingredients of carbon, manganese, phosphorus, &c.

(3.) With such valuable materials at hand, and at the disposal of all who take an interest in the questions now before us, we are enabled to institute useful comparisons, reconcile several opinions, and dilate openly on a considerable number of facts; but, on the other hand, when we come to throw a complex glance at the *ensemble* of all those works, we are struck with the great difficulty of drawing several conclusions, or formulating mathematical precise laws, the existence of which, however, we cannot fail to perceive. With the exception of carbon, the other substances, such as manganese, phosphorus, silica, &c., do not afford us—despite all the experiments made—any exact notion as to their respective action on some of the properties of steel. Moreover, and with reference to the determination of the conditions under which the experiments should be conducted, there still prevails the greatest uncertainty, on account of the difficulty of establishing exactly the relation between the results of—for example—a traction experiment and the effects produced on the same metal by flexion, tension, or concession. If, when grouping together the thousands of experiments made in various countries, made by various experimentators and on steel produced in various works, it has been hitherto impossible to attain to any confirmation of the laws connecting the physical properties of steel, and admitted in the classification of the establishments or works producing that article (laws, however, which many enlightened persons consider as having been prematurely admitted), that impossibility may be chiefly attributed to the fact that those experiments do not allow of any *direct comparison*, and that, previously to an analysis of those results. it would be necessary to make some corrections, in order to eliminate the complicated causes which affect them—the experiments not having been conducted under strictly analogous conditions. The results of the experiments of natural philosophers—say in regard to density—are referred, by way of correction, to a like atmospheric pressure and to a like temperature; but all those experiments should be referred to a similar form and size of sample, to a similar degree of elaboration of the metal, to a similar molecular condition, &c.

(4.) It must be admitted, however, that those corrections are very difficult to make, and that, in every point of view, it would be preferable to bring about a general understanding between the experimentators, the ironworkers and the engineers, as to the conditions of conducting everywhere experiments capable

of undergoing a direct comparison. The meeting of the Iron and Steel Institute having, as it has, an international character, through the presence of its members in Paris, appears to offer the most favorable opportunity for laying down the basis of a programme comprising questions relating to the resisting power of steel, and the conducting of experiments on general and analogous conditions, with the view of enabling us to institute comparisons in respect to all such experiments. Without any pretension to put forward the exact form of such a programme, we may be allowed to direct attention to a certain number of points of a nature (we think) to lead to useful discussion.

(5.) We shall not stop to point out the first difficulty one meets with, in endeavoring to compare the experiments made in different countries, viz., the varying systems of measurement, a difficulty which necessitates long calculations for the reduction of one set of figures into that of another nation. That difficulty is certainly not an obstacle, but it involves a loss of time, which might be avoided for the future; and we can only express here the hope that we shall all shortly be able, by adopting the metrical system, to express in the same figures the like facts and reports.

(6) When one has to proceed to the investigation of the physical properties of pieces or samples of steel handed to an experimentator, it would be necessary for him to know, in the first instance, in order to determine the nature of the experiments to which those pieces or samples are to be subjected, whether the object in view is to study the nature and general qualities of the steel *per se*, or to ascertain how it would act under certain given applications. In the former case it would be always necessary to test previously, by traction, the cylindrical or rectangular bars of the section and length to be determined on. In the latter case the system of experiments would depend on the nature of the application itself, and, generally speaking, the flexion and the "shock" (concussion) at the flexion will form the most useful tests.

We shall commence by examining the conditions relative to the traction experiments.

(7) In subjecting to a traction strain a steel bar of given section Ω and of length l, the facts to be observed and the quantities to be determined—if a complete experiment is to be made—should the following:—(1) During the period of perfect elasticity, the observation of the momentary elongations under given loads will allow us to determine the coefficient of the module of elasticity, E. (2) When the elongations cease to be in proportion to the loads, then the limit of elasticity is attained, load per unity of section, beyond which permanent elongations are produced, L. (3) The charge or load is increased until the rupture is produced, under a charge per unity of section, R. (4) The two portions of the broken rod are brought together, and the total length is then measured, deducting therefrom the original length; the final elongation at the rupture is then ascertained, and it is generally expressed with regard to the original length by per cent., A. (5) Then measure also the section taken by the rod at the point where the rupture has occurred. The difference between the original section and the rupture section is called, by Mr. Kirkaldy, the contraction, expressed in so much per cent. of the original section, but we prefer explaining this phenomenon of the contraction of the rupture section by the relation which the contracted section bears to the original section—that is, striction Z. (6) By dividing the total charge which produced the rupture, not by the primitive section, but by the contracted section, we have the resistance per unity of section broken $\frac{R}{2}=F$. (7) If, in a great number of trials, one is content to determine the diverse quantities above mentioned, it is nevertheless necessary, in order to have an exact and complete knowledge of the nature of any steel, to observe, in addition thereto, the permanent successive elongations made by the bar under trial, under increasing charges from the one corresponding to the limit of elasticity to the charge of rupture or breaking load. The manner in which these elongations vary, with the excess of charge on the limit of elasticity, is ordinarily represented by the aid of a "Graphic" which gives the curve of the elongations and allows of the measure-

ment being made of the work of resistance to the rupture, of which we speak hereafter. (8) Finally, it is useful, in order that the test may be complete, to describe the exact form which the bar presented after the rupture, so as to observe how the elongation was divided, and what is the exact position of the rupture section. We have to make some observations on each of those quantities.

8. COEFFICIENT OR MODULE OF ELASTICITY, E.

The modulus of elasticity is the relation of the charge to the elongations, produced during the period of perfect elasticity. It is constant during that period.

The investigation of this coefficient of elasticity for castings, iron and steel, has given rise to numerous experiments, and the figures which have been arrived at are so unlike that they cannot be brought together and compared, in order to ascertain whether, in the special point of view which we are now taking up, viz., the properties of commercial steel, we could account for the influence of the composition and of the purity of those steels on the manner in which they act during the period of perfect elasticity.

The modulus of elasticity is generally admitted at:

For castings	10,000,000,000
" iron	20,000,000,000
" steel	20,000,000,000

According to Renleaux:

Iron, in the form of bars or wires,	20,020,000,000
" in thin plates	24,010,000,000
Cast-iron	30,005,000,000
Other kinds of steel	20,020,000,000

According to Kupffer:

Flat iron, English rolled	20,010,000,000
" " " forged	20,232,000,000
" " Swedish "	21,341,000,000
Soft-cast steel	21,330,000,000

We now give the value of the modulus of elasticity resulting from the trials made by Knut Styffe:

Bessemer forged steel of	Carbon.	
H0060	1.26%	21,177,000,000
" "	1.05	21,515,000,000
Wikmanshyttan steel	1.22	21,949,000,000
Krupp "	0.61	22,046,000,000
Puddled rolled steel of Surahammar	0.56	21,033,000,000
Lowmoor puddled iron	0.30	22,480,000,000
Dudley " "	0.09	19,972,000,000
Surahammar " "	0.14	21,853,000,000
" " "	0.20	21,418,000,000
Hollstahammer rolled iron	0.07	20,357,000,000
" "	0.07	21,660,000,000

These trials already show us that the influence of the carbon is completely null in the elastic elongations produced by the same changes or loads, the coefficient of the elasticity of steels containing more than 1 per cent. of carbon is not superior to that of the irons of Motala, Surahammar, &c., which only contain 0.07 to 0.2.

When it is proved, on the other hand, that the least variations of the amount of the carbon completely modify the data of the permanent deformation, one cannot but be struck with the fact that during the period of perfect elasticity, the momentary elongations are independent of the *nature* of the metal. They appear to be modified only by the purity of the metal, and by the degree of work to which it has been subjected.

The trials or tests of Mr. Bauschinger on a series of Fernitz steels are more conclusive in that respect, because they have been made on products of the same origin, only differing with regard to the tenor of carbon and tested under the same form.

On the traction test those steels, of which the tenor of carbon varied from 0.14 to 0.96, gave:

Tenor of Carbon.	Limit of Elasticity per MM. K.	Coefficient of Elasticity. E.
0.14	29.50	22,550 millions.
0.19	33.10	21,700 "
0.46	34.50	22,550 "
0.51	34.05	22,100 "
0.54	34.90	21,550 "
0.55	33.	22,200 "
0.57	33.10	21,600 "
0.66	37.45	22,450 "
0.78	37.50	24,700 "
0.80	40.05	21,500 "
0.87	42.90	21,850 "
0.96	48.70	21,750 "
General Average		22,200 "

The experiments made at Woolwich, in 1870, by a Committee of Civil Engineers, resulted in for *steels* of various works in the limit of elasticity varying from 26 to 42ks. and the tenor of carbon of 0.30 to 0.90 per cent., an average coefficient of 20,627,000,000, the minimum being 20,160

and the maximum 21,060,000,000. Some irons tried under the same conditions gave 20,092,000,000.

From all those results, one may conclude that the coefficient of elasticity of steel, whatever may be its hardness, varies only from 20 to 22,000,000,000.

Looking at those tests in a practical point of view, we may come to the conclusion in regard to the results, that, although in some particular cases—for example, in investigating the action of manganese and phosphorus—it would not be unimportant to deduce some facts relative to the modulus of elasticity, nevertheless that part of the traction tests may be in general dispensed with, as being the most delicate, the longest in duration, and (on account of the great lengths of rod or bar required) the most expensive. Consequently, the experiments may be made on short lengths, and a larger number of tests obtained, with the same quantity of steel, within the like given time and at the like expense.

The experiments made by Professor Bauschinger on the steels of the Reschitza works (Hungary), the results of which, as well as the samples used, figure in the exhibition of the Government Railways, Austrian Company I. R. P. demonstrate how much attention and time would have to be devoted for determining certain points which after all throw no fresh light on the properties of the steels subjected to the experiments in question, inasmuch as with respect to all those steels, differing considerably as they do in regard to the tenor of carbon, the module of elasticity is comprised between 22,400,000,000 or 23,000,000,000.

We may at once state that Professor Bauschinger's experiments on the Ternitz as well as on the Reschitza steels demonstrate likewise that the module of elasticity is the same (whatever may be the hardness of the steel) at compression and flexion, and that it is represented by the same figure as the coefficient of elasticity at the traction test.

(9) *Limit of Elasticity.*—If, during the period of perfect elasticity, the elongations are in proportion to the lodes or charges, and disappear with the action of those lodes, the limit of elasticity is the equivalent ("value") of the last charge producing that effect; and under a heavier load than that limit of elasticity there is a permanent elongation.

But if there be a concordance of opinion with respect to the existence and definition of that limit of elasticity, it is otherwise with regard to the fixation of its value, for—however exact and correct the instruments employed—it is difficult to determine the precise moment at which the state of perfect elasticity passes to that of permanent deformation. More correctly speaking, the "precise moment" in question does not exist with reference to experiments on steel rods because, in point of fact, there is a period of break of elasticity, during which certain portions of the rod or bar undergo permanent elongations, whilst other portions resume their original length.

On account of the uncertainty attending the phenomenon, it is necessary to establish conventional rules for determining the limit of elasticity, and as those vary which are adopted by the various experimentalists it results that the limit of elasticity observed in respect of the same kind of bar of the same length—say in England and Sweden—will not be the same.

It is true that Wertheim and other experimenters agree in considering, as the limit of elasticity, the load or charge that produces a permanent elongation, equal to the 0.00005 of the original length, in other words—and with reference to a bar or rod of one meter—a permanent elongation of five hundredths of a millimeter; but, on the other hand, so feeble an elongation is considered by many experimenters as the possible effect of accessory causes, and they are of opinion that we cannot admit that the limit of elasticity is exceeded until such time as a more clearly defined permanent deformation is observable; and the extension under heavier loads testifies to the reality of the phenomenon.

Those considerations have led to the following special definition by Mr. Knut Styffe:

"If an iron or steel bar be gradually extended by successive loads, which at first are so small that they occasion no permanent elongation, but are gradually increased, and are always allowed to operate for as many minutes as each additional weight is per cent. of the whole load, then the author regards as the 'limit

of elasticity' that load by which, when it has been operating by successive small increments as above described, there is produced an increase in the permanent elongation which bears a ratio to the length of the bar equal to 0.01 (or approximates most nearly to 0.01) of the ratio which the increment of weight bears to the total load."

Without discussing that definition, we have only to remark that, as Mr. Knut Styffe, adhering to the opinion that the limit of elasticity cannot be considered to be attained until we can ascertain exactly, and measure the determined increments of the permanent elongation, he furnishes some estimates of the limits of elasticity considerably higher to those given in Wertheim's definition.

The following are a few examples taken from the tabular data of Mr. Knut Styffe:

	Limit of Elasticity.	
	According to the definition of Wertheim.	According to the definition of Mr. Knut Styffe.
	K.	K.
	under 16.7	20.8
Puddled iron of Motala..	" 15.8	21
" " ..	" 14.5	18.8
" " ..	" 15.3	18.8
" " ..	" 20	22.6
Puddled iron of Middlesborough-on-Tees	" 19.3	21.2
"	" 20.5	23.5
"	" 24.1	24.8
"	" 16.5	19.9
Puddled iron of Dudley.	" 16.1	20
" " .	about 28.9	51.3
Cast steel of Wilmanshyttan (carbon 1.22%).	" 28.9	51.1

The difference is from 3 to 4 kilos. in irons, and amounts to 22 kilos. in the very hard steel of Wikmanshyttan.

We only produce these figures in order to show the necessity which would exist of arriving at a mutual agreement as to the fixation of the limit of elasticity, and how imperative it is in all cases that in the publication of the series of trials the method of estimating that useful value should be pointed out.

The value of the limit of elasticity is, in point of fact, the primary manifestation of the degree of hardness or of malleability of a steel, and in many cases the basis of calculation of the dimensions of the pieces.

As, moreover, we have seen that tests on short bars are to be preferred, and that on short bars the definition of Wertheim cannot be applied, whilst, on the other hand, the definition of Mr. Knut Styffe appears to us to give too high a quotation of figures, one can see what interest would be attached to a plain agreement on the subject, easily formed and adapted to the tests of short bars.

MENTAL LOGARITHMS.—Some years ago, about 1863, Mr. Oliver Byrne, formerly Professor of Mathematics in the College of Civil Engineers at Putney, discovered an entirely new and ingenious method of arithmetical calculation of great practical importance to Engineers and others, and which was claimed to enable any one acquainted with the ordinary rules of common arithmetic to extract the roots of cubics, equations of the fifth degree, and higher equations; to determine angular magnitude and trigonometrical lines, to solve plane triangles without the use of tables, and, generally, to deal with almost innumerable problems which had previously been considered to require great mathematical skill, and an intimate acquaintance with the higher branches of the science. But owing to the discoverer having adopted a peculiar and unfamiliar system of notation in explaining the art, many have regarded the whole subject as unintelligible, if not useless. A complete remedy for this has now been found by Mr. Edward David Hearn, M.A., of Columbia College, New York, whose name is already known to mathematicians, as the author of an extension of Horner's method for the synthetic division of algebraic quantities with detached co-efficients, and of an elucidation of Suffield's method of arithmetical synthetic division. Mr. Hearn contributes to the October number of *Scientific Review*, an interesting paper on "Mental Logarithms," in which he demonstrates that all the developments of which Mr. Byrne's art is capable, are not only practicable without any departure from the ordinary Arabic notation, with which every schoolboy is familiar, but that the common notation really increases the speed at which the calculations on the new system can be performed.

AUSTRIAN GUN EXPERIMENTS.—The Budget Committee of the Austrian Delegation have rejected the items of 1,712,000 florins proposed for the adaptation of the Werndl rifles to stronger cartridges, 250,000 florins for experiments in the manufacture of steel and bronze guns, and 200,000 florins for providing twenty-five heavy guns for arming forts and for repairs in fortresses.

WATER-PRESSURE MACHINERY EMPLOYED FOR WATER SUPPLY.

By C. KROBER.

From "Der Praktische Maschinenconstructeur," Abstracts published by the Institution of Civil Engineers.

The water supply of Sigmaringen Castle, the residence of Prince Charles Antony of Hohenzollern, was formerly obtained from a source on the left bank of the Danube by means of pumps driven by a water-wheel. Owing to the imperfect construction of the machinery and the limited power, the water could not be raised to the upper storeys of the buildings. Improved machinery was therefore erected in October, 1876, the Roman tower, situated about the centre of the castle, being chosen as the most convenient place for the reservoir.

The highest water level of this reservoir was 183.5 feet above that of the source, and about 203 feet above the Danube. The quantity of water required to be lifted per second was 0.408 gallon, and the total quantity of water supplied by the source 10.867 gallons per second; thus there remained for the motor $10.867 - 0.408 = 10.459$ gallons. The fall from the level of the source to the discharge of the proposed water motor was 13.1 feet. Taking the resistance of friction in the existing pressure pipe (of 4 inches diameter and 2,450 feet length) as equivalent to a loss of height of about 9.8 feet, the effective work to be done by the machinery was $0.408 \times 10 \times 193.3 = 788.6$ foot lbs.

The available water power $10.46 \times 10 \times 13.1 = 1370$ foot lbs. The machinery was therefore required to utilize $\frac{788.6}{1370} \times 100 = 57\frac{1}{2}$ per cent. of the available water power.

The application of a turbine with intermediate gearing would have occasioned a loss of effect amounting to at least 40 per cent.; a water-wheel would only have lost about 32 per cent. Adding to this a loss of effect of 15 per cent. by the pumps, the effect of the whole machinery was estimated at 55 per cent. These considerations induced the engineer to use direct-acting water-pressure machines, and although these had probably not yet been applied for so small a head of water (13 feet), no doubt was entertained as to their superiority over turbines or water-wheels. Experiments on the loss of effect arising from friction of the pistons and from other sources, were made by Messrs. Sulzer Brothers, and the result justified them in undertaking the construction of the machines under guarantee to lift 0.408 gallon of water per second into the high level reservoir with the available water power.

To enable repairs being made without a complete interruption of the water supply, the machinery was constructed in duplicate. The machines were arranged horizontally, the pumps were single-acting plunger pumps, the piston rods of the motor serving as plungers of the pumps. By attaching the pump cylinders immediately to the covers of the central or pressure cylinder, only one stuffing box was required on each side of the motor to separate the two water spaces.

The starting of the machinery completely justified the expectations of the engineer. The measurements and experiments made by him showed, that for the normal work it was necessary to throttle the headwater, and that the required quantity of 0.408 gallon could be pumped into the reservoir by 9.8 gallons of water at a pressure corresponding to a height of 10.66 feet. Taking again the resistance of friction in the tubes as equivalent to a loss of height of 9·8 feet, the machines utilize

$$\frac{0.408 \times 193.3}{9.8 \times 10.66} \times 100 = 75$$

per cent. of the consumed water power.

The indicator diagrams taken from the pumps as well as from the pressure cylinder, showed a perfect uniformity of pressure. The pressure pistons have 1 foot $3\frac{1}{4}$ inches, and the pump pistons $3\frac{1}{4}$ inches diameter. The stroke is 3.3 feet.

THE STRENGTH OF MATERIALS.

By WILLIAM KENT, M.E., Pittsburgh, Pa.

Written for VAN NOSTRAND'S MAGAZINE.

II.

COMPRESSIBLE STRESS.

A compressive stress, or push, applied to a piece of material is a force which tends to shorten it. In testing the compressive resistance of metals or other materials, testing machines similar to those used in tests of tensile resistance are used, or the tensile machine may be adapted to compressive tests by means of a couple of yokes or like mechanical device.

What is meant by the term "compressive strength" has not yet been settled by the authorities, and there exists more confusion in regard to this term than in regard to any other used by writers on strength of materials. The reason of this may be easily explained. The effect of a compressive stress upon a material varies with the nature of the material, and with the shape and size of the specimen tested. While the effect of a tensile stress is always to produce rupture or separation of particles in the direction of the line of strain, the effect of a compressive stress on a piece of material may be either to cause it to fly into splinters, to separate into two or more wedge-shaped pieces and fly apart, to bulge, buckle or bend, or to flatten out and utterly resist rupture or separation of particles. A piece of speculum metal under compressive stress will exhibit no change of appearance until rupture takes place, and then it will fly to pieces almost as suddenly as if blown apart by gunpowder. A piece of cast iron or of stone will generally split into wedge-shaped fragments. A piece of wrought iron will buckle or bend. A piece of wood or of zinc may bulge, but its action will depend upon its shape and size. A piece of lead will flatten out and resist compression till the last degree; that is, the more it is compressed the greater becomes its resistance.

Air and other gaseous bodies are compressible to any extent, as long as they retain the gaseous condition. Water, not confined in a vessel, is compressed by its own weight to the thickness of a mere film, while when confined in a vessel it is almost incompressible. It is probable, although it has not been determined experimentally, that solid bodies when confined are at least as incompressible as water. When they are not confined, the effect of a compressive stress is not only to shorten them, but also to increase their lateral dimensions or bulge them. Lateral strains are therefore induced by compressive stresses.

The weight per square inch of original section required to produce any given amount or percentage of shortening of any material is not a constant quantity, but varies with both the length and the sectional area, with the shape of this sectional area, and with the relation of the area to the length. The "compressive strength" of a material, if this term be supposed to mean the weight in pounds per square inch necessary to cause rupture, may vary with every size and shape of specimen experimented upon. Still more difficult would it be to state what is the "compressive strength" of a material which does not rupture at all, but flattens out. Suppose we are testing a cylinder of a soft metal like lead, two inches in length and one inch in diameter, a certain weight will shorten it one per cent., another weight ten per cent., another fifty per cent., but no weight that we can place upon it will rupture it, for it will flatten out to a thin sheet. What then is its compressive strength? Again, a similar cylinder of soft wrought iron would probably compress a few per cent., bulging evenly all around, it would then commence to bend, but at first the bend would be imperceptible to the eye and too small to be measured. Soon this bend would be great enough to be noticed, and finally the piece might be bent nearly double, or otherwise distorted. What is the "compressive strength" of this piece of iron? Is it the weight per square inch

which compresses the piece one per cent., or five per cent., that which causes the first bending (impossible to be discovered), or that which causes a "perceptible" bend?

So confusing is this whole matter of compressive strength that there is scarcely a single published figure on the compressive strength of wrought iron that can be relied upon. Wood's resistance of materials has the following:

"Comparatively few experiments have been made to determine how much wrought iron will sustain at the point of crushing. Hodgkinson gives 65,000, Rondulet 70,800, Weisbach 72,000, Rankine 30,000 to 40,000. It is generally assumed that wrought iron will resist about two-thirds as much crushing as to tension, but the experiments fail to give a very definite ratio."

Mr. Whipple, in his treatise on bridge building, states that a bar of good wrought iron will sustain a tensile strain of about 60,000 pounds per square inch, and a compressive strain, in pieces of a length not exceeding twice the least diameter, of about 90,000 pounds.

In a "Pocket Companion" of tables appertaining to the use of wrought iron, published by Carnegie Bros. & Co., of Pittsburgh, the following values are given in a table of crushing strength of materials, said to be deduced from the experiments of Major Wade, Hodgkinson, and Capt. Meigs:

American wrought iron,		127,720	lbs.
"	" " mean	83,500	"
English	" "	65,200	"
		40,000	"

On the page next after this table is the following:

"Experiments upon wrought iron give a mean crushing stress [strength] of 74,250 lbs. per square inch."

When the best authorities differ so widely in their views of the compressive strength of wrought iron, can it be wondered that engineers have so long hesitated to use the material in compression, and that when they do use it they dare not use it with economy? If the United States Board appointed to test Iron and Steel, which seems to be about to close its labors for want of an appropriation to continue them, were to do nothing else than investigate this matter of the compressive strength of wrought iron, and establish rules governing its use to resist compressive forces in structures, they would confer a benefit on the country and the world which would be worth ten times the amount of the appropriation necessary for the whole work.

Stoney states that the strength of short pillars of any given material, all having the same diameter, does not vary much, provided the length of the piece is not less than one, and does not exceed four or five diameters, and that the weight which will just crush a short prism whose base equals one square inch, and whose height is not less than 1 to 1½ and does not exceed 4 or 5 diameters, is called the *crushing strength* of the material. It would be well if experimenters would all agree upon some such definition of the term "crushing strength," and insist that all experiments which are made for the purpose of testing the relative values of different materials in compression be made on specimens of exactly the same shape and size. An arbitrary size and shape should be assumed and agreed upon for this purpose. The size mentioned by Stoney is definite as regards area of section; *viz*: one square inch, but is indefinite as regards length; *viz:* from 1 to 5 diameters. In some metals a specimen of 5 diameters long would bend, and give a much lower apparent strength than a specimen having a length of 1 diameter. The words "will just crush" are also indefinite for ductile materials, in which the resistance increases indefinitely if the piece tested does not bend. In such cases the weight which causes a certain percentage of compression, as five, ten, or fifty per cent. should be assumed as the crushing strength.

For future experiments on crushing strength, three things are desirable; first, an arbitrary standard shape and size of test specimen for comparison of all materials; secondly, a standard limit of compression for ductile materials, which shall be considered equivalent to fracture in brittle materials; thirdly, an accurate knowledge of the relation of the crushing strength of a specimen of standard shape and size to the crushing strength of specimens of all other shapes and sizes. The latter can only be

secured by a very extensive and accurate series of experiments upon all kinds of materials, and on specimens of a great number of different shapes and sizes. Hodgkinson has been the chief experimenter in this direction, but his researches have not been nearly so extensive as to give us all the desirable information on this point. A standard size for compression tests, and a standard limit of compression, assumed equivalent to fracture, have never yet been agreed upon and have probably never even been proposed.

The writer proposes, as a standard shape and size for a compressive test specimen for all materials, a cylinder one inch in length, and one half square inch in sectional area, or 0.798 inch diameter; and for the limit of compression equivalent to fracture, ten per cent. of the original length. The term "compressive strength," or "compressive strength of standard specimen," would then mean *the weight per square inch required to fracture by compressive stress a cylinder one inch long and* 0.798 *inch diameter, or to reduce its length to* 0.9 *inch if fracture does not take place before that reduction in length is reached.* If such a standard, or any standard size whatever, had been used by the earlier authorities on the strength of materials, we never would have had such discrepancies in their statements in regard to the compressive strength of wrought iron as those given above

The reasons why this particular size is recommended are, that the sectional area, one half square inch, is as large as can be taken in the ordinary testing machines of 100,000 pounds capacity, to include all the ordinary metals of construction, cast and wrought iron and the softer steels; and that the length, one inch, is convenient for calculation of percentage of compression. If the length were made two inches many materials would bend in testing, and give incorrect results. Even in cast iron, Hodgkinson found as the mean of several experiments on various grades, tested in specimens $\frac{3}{4}$ inch in height, a compressive strength per square inch of 94,730 pounds, while the mean of the same number of specimens of the same irons tested in pieces $1\frac{1}{2}$ inches in height, was only 88,800 pounds. The best size and shape of standard specimen should, however, be settled upon only after consultation and agreement among several authorities. The United States Board appointed to test Iron, Steel, etc., or the American Society of Civil Engineers might easily fix upon such a standard.

After fixing upon a standard test piece, by which all materials might be compared, tests should be made of all sizes and shapes other than the standard, to determine what relation existed between their apparent strength per square inch and that of the standard. When these results were obtained and formulated, a test might be made of any material of any shape and size, and by applying the formulæ of reduction, the "compressive strength of standard specimen" be predicted, and from the latter could be calculated the strength of any shape and size which it might be proposed to use in a structure.

Some of the results already obtained in the direction of determining the relation of length and diameter to apparent compressive strength will now be given; taken chiefly from Wood's Resistance of Materials.

As above stated, in Hodgkinson's experiments the increase of the length of test specimens decreased the apparent compressive strength per square inch from 94,730 to 88,800 pounds.

Fairbank and Tate, in testing small cubes and cylinders of glass, found a compressive strength for the cubes of 18,401 and for the cylinders of 30,153 pounds per square inch.

Hodgkinson, in experiments on long square pillars, found that the compressive strength varied as the 3.59 power of the side of the square, as a mean result; the extremes being the 2.69 and the 4.17 powers. From his experiments, the following table of the absolute strength of columns was obtained, in which

P = crushing weight in gross tons.

d = the side of the column in inches, or external diameter.

d_1 = the internal diameter of the hollow, in inches.

l = the length in feet.

Kind of column.	Both ends rounded the length of the column exceeding 15 times its diameter.	Both ends flat, the length of the column exceeding 30 times its diameter.
Solid cylindrical columns of cast iron.....	$P=14.9\frac{d^{3.76}}{l^{1.7}}$	$P=44.16\frac{d^{3.55}}{l^{1.7}}$
Hollow cylindrical columns of cast iron....	$P=13\frac{d^{3.76}-d_1^{3.76}}{l^{1.7}}$	$P=44.34\frac{d^{3.55}-d_1^{3.55}}{l^{1.7}}$
Solid cylindrical columns of wrought iron.....	$P=42\frac{d^{3.76}}{l^2}$	$P=133.75\frac{d^{3.55}}{l^2}$
Solid square pillar of Dantzic oak.....	.....	$P=10.95\frac{d^4}{l^2}$

The above formulas apply only in cases in which the length is so great that the column breaks by bending and not by simple crushing. If the column be shorter than that given in the table, and more than four or five times its diameter, the strength is found by the following formula:

$$W=\frac{PCK}{P+\frac{3}{4}CK}$$

in which

P=the value given in the preceding table.

K=the transverse section of the column in square inches.

C=the modulus for crushing in gross tons per square inch.

W=the strength of the column in gross tons.

The "modulus of crushing" is defined by Prof. Wood as "the pressure which is necessary to crush a piece of any material whose section is unity and whose length does not exceed from one to five times its diameter"—a very indefinite quantity, as already shown in the case of wrought iron!

Prof. Wood states that it is found by experiment that the resistance of short pieces (blocks) to crushing varies nearly as the transverse section of the piece. Gen. Gillmore, however, in experiments on stone, found that the strength per square inch of section of cubes of different sizes varied nearly as the cube root of the side of the cube.

In some experiments made by Mr. J. Tangye on the compressive strength of wrought iron, a bar of soft Lowmoor iron, 8 or 9 inches long, was planed on opposite sides to a thickness of $\frac{3}{4}$ inch, and subjected to pressure on one side under a steel die $\frac{1}{2}$ inch square. The following are the results of the tests, and they prove clearly that a unit of iron has a much greater power of resistance when it forms part of a large mass than when it is isolated in the manner customary in experiments on compression:

Load per square inch.

20 tons, no impression.

24 " slightest indentation, sensible to finger nail.

28 " indentation visible, edge followed by finger nail.

40 " indented about $\frac{1}{64}$th of an inch.

These experiments certainly throw a doubt upon the statement that the resistance of short pieces varies as the transverse section.

Gordon's Rules for Flexible Columns. (From Clark).—The first and second formulas given below were deduced by Lewis D. Gordon, from the results of Hodgkinson's experiments. As here given, they show the total breaking weight of a cast iron column. The succeeding formulas for strength of columns of wrought iron and steel were constructed on the basis of Gordon's formula by the authorities named.

For solid or hollow round cast iron columns $W=\frac{36a}{1+\frac{r^2}{400}}$

For solid or hollow rectangular cast iron columns $W=\frac{36a}{1+\frac{r^2}{500}}$

For solid rectangular wrought iron

columns $W=\frac{16a}{1+\frac{r^2}{5000}}$ (Stoney).

For columns of angle, tee, channel, or cruciform iron $W=\frac{19a}{1+\frac{r^2}{900}}$ (Unwin).

For solid round column of mild steel

$$W=\frac{30a}{1+\frac{r^2}{1400}} \quad \text{(Baker).}$$

For solid round column of strong steel

$$W=\frac{51a}{1+\frac{r^2}{900}} \quad \text{(Baker).}$$

For solid rectangular column of mild steel $W=\frac{30a}{1+\frac{r^2}{2480}}$ (Baker).

For solid rectangular column of strong steel $W=\frac{51a}{1+\frac{r^2}{1600}}$ (Baker).

In these formulas W=the breaking weight in tons of 2240 lbs., a=sectional area of the material in square inches, r= the ratio of the length to the diameter, the diameter being the least dimension of the section or that in which it is most flexible.

The pocket book of Carnegie Bros. & Co. (mentioned above) gives a formula for the strength of wrought iron columns, based upon Gordon's formula as follows:

$$W=\frac{FA}{1+\frac{1}{4500}\left(\frac{l}{h}\right)2}:$$

in which W=breaking load in pounds, F=36000 pounds, A=sectional area of column in square inches, l=its length in inches, and h=its diameter in inches.

A similar pocket book, by the Phœnix Iron Co., of Philadelphia, gives the formula in this shape:

$$W=\frac{FA}{1+\frac{1}{3000}\left(\frac{l}{h}\right)^2}$$

in which F=50000 pounds.

The following example will show the discrepancies in results obtained by these two formulas and the one of Stoney:

Given a wrought iron column one inch square in section and ten inches long. Required its breaking weight?

A=1 square inch. $\frac{l}{h}=r=10.$ $r^2=10.$

$W=\frac{16\times1}{1+\frac{100}{3000}}=15.489$ tons=34,695 lbs. (Stoney).

$W=\frac{36000\times1}{1+\frac{100}{45000}}$ = ... 35,218 lbs. (Carnegie Bros. & Co).

$W=\frac{50000\times1}{1+\frac{100}{3000}}$ = ... 48,389 lbs. (Phœnix Iron Co).

showing a difference of nearly 40 per cent. between the lowest and highest results. The columns of a building which were designed with the use of one of these formulas might cost 40 per cent. more than if designed with the use of another.

Enough has now been given to show that our knowledge of the subject of compressive strength is very indefinite and unreliable. The greatest necessity exists for a comprehensive series of experiments which shall serve as a standard for reference and comparison. Such experiments would be too costly to be undertaken by any individual, and as the matter is of national importance, it is well worthy the attention of the government.

In making experiments upon compressive strength, even greater care is required than in experiments on tensile strength. In tensile tests, the tendency of a ductile specimen is always to pull into the line of strain, and this to some extent (but not entirely) corrects the error caused by wrongly placing the piece in the testing machine. In compressed tests the tendency is just the reverse; the effect of a push is always to cause the piece to tend to bend out of the line of strain, and this can only be prevented by having the line of strain pass exactly through the axis of the specimen. The test specimen should, therefore, be placed in the machine with the utmost accuracy, care should be taken that the bearing of the piece on the compression blocks is a true one, and that in pulling or pushing together the compression blocks they shall have no tendency

to move sidewise or in any other direction than that of the line of strain.

TRANSVERSE STRESS.

Tests by transverse stress are in general much more easily made than tests by either tensile or compressive stress. An elaborate testing machine is not necessary. The bar or beam to be tested is placed on two supports, which are a measured distance apart and perfectly level, and weights applied to the middle till the piece breaks. Steel rollers are frequently used for supports, rolling on a horizontal plane and kept a constant distance apart during the test. The use of rollers obviates the error due to friction of the bar upon the supports when the latter are fixed.

In testing bars which require considerable weight to break them, some mechanical appliance has to be used to assist in placing the weights on the bar without shock. A testing machine, designed for transverse tests alone, built by Messrs. E. & T. Fairbanks & Co. for the Mechanical Laboratory of the Stevens Institute of Technology, consists of an ordinary platform scale, with a heavy timber foundation, carrying a heavy cast iron beam with two cast iron supports which may be placed any distance apart up to five feet. The bar to be tested rests on rollers, and the pressure is applied by means of a screw. This machine was largely used in the experiments on strength of alloys, made by the United States Board appointed to test iron, steel, etc., and a complete description of it will appear in the report on these tests when published. It has been used up to 7,000 pounds pressure, and it will test bars up to five feet in length. Measurements of deflection are made to the $\frac{1}{10000}$ of an inch by means of the micrometer screw apparatus, with electrical contact, which was described under the head of tensile tests. By this machine and measuring apparatus very important scientific results have been obtained in reference to the effect of time upon tests, in elevating the elastic limit and in causing increase of deflection and decrease of set, which are described at length by Prof. Thurston in the Transactions of the American Society of Civil Engineers, 1875 and 1876.

The new 40,000 pound tensile testing machines, built by Riehle Bros. of Philadelphia, have attachments by which transverse tests may be made on bars 12 inches in length between supports, and the new 100,000 pound machine of John L. Gill, Jr., of Pittsburgh, has a transverse attachment that will take a bar of any length from 10 to 40 inches. The manufacturers of wrought iron beams have had tests made and published in their "pocket books of information" on the transverse strength of their beams, the results of which tests may in general be relied on for practical purposes. There exists no such discrepancy in published figures of transverse strength of beams as that which has been shown to exist in figures of the compressive strength of columns.

In recording results of transverse tests, it is important sometimes to note the time taken in the tests. A remarkable instance of the increase of apparent strength of wrought iron, by keeping it under strain for three weeks, has already been noted in discussing the influence of time upon tensile tests. Bars of tin and of ductile alloys will show a much less transverse strength if considerable time is taken in testing than if the test is made rapidly, while the reverse is true in tests of wrought iron and soft steel.

The effect of time in a transverse test, varies according to the method of testing. In testing by dead loads the load remains constant, and if the bar is strained beyond its elastic limit the deflection may increase with time. This increase of deflection may continue for several minutes or for several days and then entirely cease; or it may continue with increasing rapidity until the bar breaks or bends. In Prof. Thurston's tests by transverse stress some curious phenomena have been observed. The rate of increase of deflection in some instances grew smaller and smaller for several hours, then for a while it remained constant, and then increased till the bar broke. It would appear as if there was a certain definite deflection for each material, after passing which a continuance of the load which caused it will increase the deflection indefinitely, at an increasing rate, until bending or rupture takes place, but that before that deflection is reached the rate of increase of deflection

will be a decreasing one, tending to a cessation of that increase.

In testing by a pressure screw and platform scale, or similar testing machine, the action of a dead load is imitated only when the machine is so operated as to keep the scale beam constantly balanced, the deflection meanwhile increasing, as the pressure screw requires to be advanced to keep the beam balanced. If the pressure screw is not advanced, and the deflection is therefore held constant, the bar will exhibit a decrease of resistance to that deflection, which decrease, in every ductile and non-elastic material, will continue with a decreasing rate until the deflection has become a permanent set, and the scale beam indicates no resistance at all; in elastic materials the decrease of resistance will soon cease, and the bar, acting like a perfect spring, will keep the scale beam balanced at a figure somewhat below that indicating the load which primarily caused the deflection. In a perfectly elastic material, as hard steel or glass, no decrease of resistance (or only a very slight one) takes place. The study of these phenomena opens an interesting and almost unexplored field of physical research.

A standard size and shape of test specimen would be desirable for transverse tests, but it is not so necessary as in compressive or tensile tests, since the relation existing between the dimensions of bars and both their ultimate strength and deflection under loads has been determined, both mathematically and by experiment. The strength of bars of rectangular section is found to vary directly as the breadth of the specimen tested, as the square of its depth, and inversely as its length. The deflection under any load varies approximately as the cube of the length, and inversely as the breadth and as the cube of the depth. Represented algebraically, if S = the strength and D the deflection, l the length, b the breadth, and d the depth.

$$\text{S varies as } \frac{bd^2}{l} \text{ and D varies as } \frac{l^3}{bd^3}.$$

For the purpose of reducing the strength of pieces of various sizes to a common standard the term *modulus of rupture* (represented by R) is used. Its value is obtained by experiment on a bar of rectangular section supported at the ends and loaded in the middle and substituting numerical values in the following formula

$$R = \tfrac{3}{2}\frac{Pl}{bd^2} \text{ in which}$$

P = the breaking load in pounds, l = the length in inches, b the breadth, and d the depth.

The *modulus of rupture* is sometimes defined as the strain at the instant of rupture upon a unit of the section which is most remote from the neutral axis on the side which first ruptures. This definition, however, is based upon a theory which is yet in dispute among authorities, and it is better to define it as a numerical value found by application of the formula above given.

Knowing the value of R for any material the weight necessary to break a beam of that material, loaded in any of the ways specified below may be found from the following formulas:

For a beam fixed at one end and a load P at the other

$$P = \tfrac{1}{6}\frac{Rbd^2}{l} \qquad (1)$$

The same beam with a load W uniformly distributed over the length

$$\tfrac{1}{2}W = \tfrac{1}{6}\frac{Rbd^2}{l} \qquad (2)$$

Beam supported at its ends and loaded in the middle

$$P = \tfrac{2}{3}\frac{Rbd^2}{l} \qquad (3)$$

Beam supported at its ends and loaded uniformly

$$P = \tfrac{4}{3}\frac{Rbd^2}{l} \qquad (4)$$

Beam fixed at both ends and loaded in the middle

$$P = \tfrac{4}{3}\frac{Rbd^2}{l} \qquad (5)$$

Beam fixed at both ends and loaded uniformly

$$P = \frac{2Rbd^2}{l} \qquad (6)$$

These formulas are all deduced mathematically (see Wood's Resistance of Materials) and are confirmed by experiment, except the last two, in which it seems that

the mathematical investigation has not included all the conditions, for Mr. Barlow found by experiment that equation (5) should be $P=\frac{Rbd^2}{l}$.

The value of R for any material depends upon the tensile and the compressive strength, and if these (per square inch) are not equal it is always greater than the one and less than the other. In testing a beam by transverse stress (supported at the ends) the upper side is compressed and the lower side is extended, the surface located at some position between the compressed and extended sides, which receives no strain, being called the neutral axis, or neutral surface.

The strength of beams of other than rectangular section, the deflection of beams of various shapes and sizes, the relation existing between transverse strength and tensile and compressive strength, and many other interesting branches of the subject of transverse strength are treated of at great length by various authorities, but the limits of this paper will not allow of more than a mere mention of them here. A recent work entitled "Transverse Strain," by R. G. Hatfield, is an invaluable book for architects and others interested in the subject of which it treats, who are not professional engineers. Various theories of the relation between transverse strength and tensile and compressive strength are found in works on resistance of materials. A theory on this subject is given by the writer in a note published in VAN NOSTRAND'S MAGAZINE, October, 1877.

SHEARING STRESS.

Shearing stress is a force tending to draw one part of a solid substance over another part of it; the applied and resisting forces acting in parallel planes which are very near to each other. It acts like a pair of shears. Materials under a variety of circumstances are subjected to this stress—as rivets in riveted plates, pins and bolts in spliced joints, beams subjected to transverse stress, bars which are twisted, and in short all pieces which are subjected to any kind of distorsive stress in which all parts are not equally strained. Shearing may take place in detail, as when plates or bars of iron are cut with a pair of shears, when only a small portion is operated upon at a time; or it may be done so as to bring into action the whole section at a time, as in the process of punching holes into metal, where the whole convex surface of the hole is supposed to resist uniformly.*

The total resistance to ultimate shearing, when all parts of the resisting surface are brought into action at once, is found to vary directly as the section. The experiments on large sections, however, have not been sufficiently numerous to make this certain for all cases. From a table of shearing strength of various metals, given in Good's "Resistance of Materials," on the authority of various experimenters, it appears that the shearing strength of wrought iron is about the same as its tenacity, of cast steel it is a little less than its tenacity, of cast iron it is double its tenacity and about $\frac{2}{3}$ its crushing resistance, and of copper it is about $\frac{2}{3}$ its tenacity. Clark considers that the shearing strength of wrought iron may be taken at about $\frac{4}{5}$ of its tenacity. Clark also gives the following: "Rankine states that the shearing strength of cast iron is 12.37 tons per square inch; Stoney found by experiment, that it varied from 8 to 9 tons per square inch. Both may be correct, as cast iron is very variable in tensile strength. It is probable that its shearing resistance is by reason of its comparative incompressibility equal to its direct tensile resistance."

Engineer-in-Chief, William H. Shock, U. S. N., found that the shearing resistance of ordinary round bar iron of commerce averaged 17.81 tons, or 39894 pounds per square inch, on bolts of from $\frac{1}{2}$ inch to 1 inch diameter.

M. C. Little found the resistance to shearing by parallel cutters of bars 3 inches by $\frac{1}{2}$ inch and 1 inch thick, and to punching 1 and 2 inch holes through bars $\frac{1}{2}$, 1 and $1\frac{1}{2}$ inches thick, varied from 19 to 22.35 tons per square inch of area cut.

In view of the conflicting statements given above, it may well be supposed that our knowledge on the subject of shearing resistance is almost as indefinite as that of compressive resistance. Some light is thrown upon the reason of the

* Wood's "Resistance of Materials."

discrepancies by the following fact, taken from Clark:

"Oak treenails firmly held, of from 1 to $1\frac{3}{4}$ inch diameter, were found by Mr. Parsons to have a shearing strength of about two tons per square inch of section. For the development of so much resistance, Rankine deduces that the planks connected by the treenails should have a thickness of at least three times their diameter. Treenails of $1\frac{3}{4}$ inches diameter in a three inch plank, bore only 1.43 tons per square inch, and in a six inch plank 1.73 tons."

Here it is plainly shown that the strength of the treenail depended not only on its diameter, but also on the bearing it had in the plank, and it seems almost certain, therefore, that the varying firmness of the bearings used by different experimenters has been the cause of the discrepancies in their results. The following illustration may show how different results might be obtained on the same piece of iron:

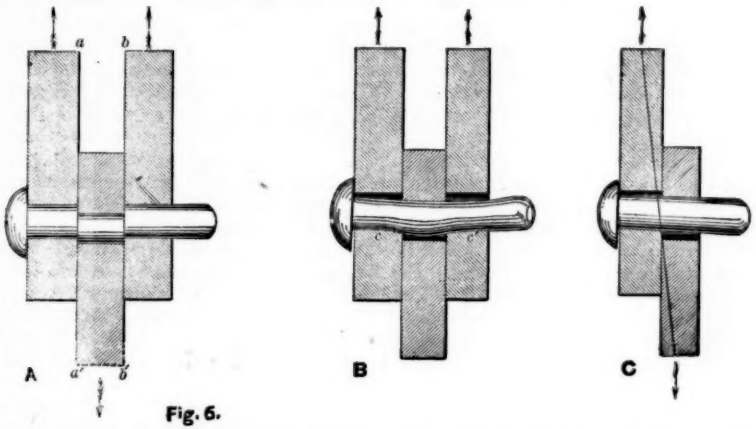


Fig. 6.

A represents a case of true double shearing. The iron bolt is being sheared off directly in the lines of the sliding surfaces *aa'* and *bb'*, the sliding plates being of hardened steel with true corners. Test B might appear exactly like test A to the ordinary observer if the bending, which is exaggerated in the cut, were very slight. The only difference here is, that the sliding plates are of soft iron, and the bolt fits itself to a bearing along the lines *cc'*, and the result is a combination of tensile, shearing and bending stresses. It would be impossible to say from such a test as this, what the actual shearing strength of the bolt would be. C represents a case of single shearing in which plates of soft iron are used with a similar effect to that shown in B, but still worse. The dotted line shows that the line of strain of the testing machine is at an angle to the line of sliding, which further complicates the result.

A committee of the American Railway Master Mechanics' Association, made the following experiments on riveted plates:

Six pieces $1\frac{3}{4}$ inches wide and $\frac{5}{16}$ inch thick, cut from the same sheet, were punched and riveted together with the best $\frac{5}{8}$ inch rivets, one rivet to each pair, with the following results:

	lbs.
No. 1 broke in center line of hole under	17,828
No. 2 " " " "	17,828
No. 3 " " " "	17,143
The average breaking strain being	17,599

Six pieces, duplicates of those last mentioned, were *drilled* and riveted together, one $\frac{5}{8}$ inch rivet to each pair.

No. 1	*sheared the rivet* under	17,143 lbs.
No. 2	" "	16,457 "
No. 3	" "	15,428 "

The average *shearing* strain being 16,342

Prof. Wood remarks concerning these tests, that "it is evident that drilled holes cause the rivets to be sheared more easily than punched ones." If these sets of tests are considered as tests of the

strength of $\frac{5}{8}$ inch rivets, the latter set show the rivets to have an average strength of 16,342 pounds, or 53,231 pounds per square inch, while the former shows their average to be *more than* 17,599 pounds, or 57,326 pounds per square inch. Different methods of testing, therefore, give different results. Which is the correct method? And how many tests of which the results are published were made by the correct method?

The writer is not aware that any standard method of making tests of shearing strength, or standard size of test specimens, has ever been proposed. For testing the transverse shearing strength of bolts and rivets, the use of the double shearing plates, shown at A Fig. 6, is probably the best method; the plates being made of hardened steel, and the holes drilled in them just large enough to allow the bolt to enter with a sliding fit. The best thickness of the plates or the relation of thickness to the diameter of the holes would have to be determined by experiment before the proper standard could be fixed, as the tests of treenails by M. Parsons, above mentioned, show that the thickness of the bearing has an influence upon the results. As it is not entirely certain that the resistance of various sections of the same material to shearing stress is exactly proportional to the area of section, experiments to determine the relation of shearing resistance to area of section and determine the best size and shape for a standard test specimen are needed, in order that the results obtained by different experimenters may be compared.

It has been stated above that in the process of punching metal the "whole convex surface of the hole is supposed to resist uniformly." This is probably true only in punching thin plates. In punching bars, blocks or nuts whose thickness exceds the diameter of the punch, it is found that the punch may be entered into the upper side of the metal a considerable distance before the lower side of the plate shows any signs of being strained. This was plainly shown in some experiments on punching made by Mr. David Townsend, published in the *Journal of the Franklin Institute*, for March, 1878. In these experiments rectangular blocks of iron $1\frac{3}{4}$ inches thick were punched only partly through, and then, after withdrawing the punch and planing away one-half of the metal to a plane passing through the axis of the hole, it was found that the effect of the partial punching was to crowd the portion of metal displaced by the punch into those portions beneath and around the hole, but that when the punch had not entered more than half the thickness of the block the fibers of the metal at the bottom of the block appeared to be uninfluenced in any way by the punching. It seems evident from these experiments that the resistance to punching is not simply resistance to shearing, but is compounded with compressive resistance, and that the convex surface of the hole therefore does not resist uniformly and simultaneously, but to some extent in detail, or one portion after the other.

It would appear probable, also, that in shearing large bolts, or large sections of any kind, that the whole section may not resist simultaneously. If this is the case large sections would show a less apparent shearing strength per square inch than small sections. The relation of resistance to section may also vary with the nature of the material.

It is plain that the subject of shearing strength is a complex one, and further experiments are required to render our knowledge upon it at all definite and reliable.

TORSIONAL STRENGTH.

A torsional stress applied to a piece of material is a force that tends to turn or twist it. In all cases in which a force is applied at one point on a shaft to turn it, and there is a resisting force at another point, the shaft is subjected to torsional strain. The wheel and axle is an example. To produce torsion without bending, a *couple*, whose axis coincides with the axis of the piece, must be applied to it. If only a single force is applied, the result is a combined bending and twisting. A hand-wheel, operated by two hands placed exactly opposite on the rim, and each hand exerting the same effort to turn the wheel, is an example of the application of a couple. A hand-wheel operated by only one hand on the rim is an example of the application of a combined bending and twisting force.

A torsional stress tends to break a

piece by combined shearing and tensile stresses. In twisting a rope, for instance, it is plainly seen that rupture will take place by tension of the fibers. In twisting certain metals, such as soft steel, the piece appears to break chiefly by shearing, the fracture being a comparatively plane surface, perpendicular to the axis of the piece.

The exact relation between torsional strength and tensile and shearing strength has not yet been determined, but approximate theoretical relation may be derived mathematically, and still closer approximations to the true relation may be obtained by experiment. The relation varies with the ductility of the material. In a material which is perfectly elastic until rupture the resistance of each fiber varies directly as its distance from the axis of the piece. In a material which is very ductile, the final resistance of each fiber is nearly the same, whatever its distance from the axis of the piece. Of two pieces of metal of the same size and the same tensile and shearing strength, the one which is the more ductile will offer the greater resistance to torsion.

Resistance to torsion is expressed in

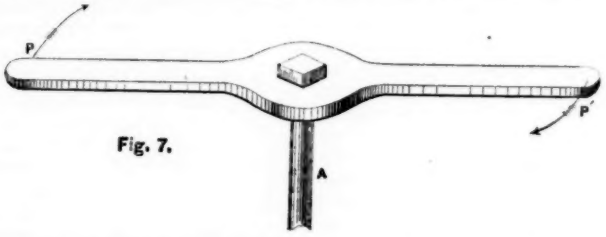


Fig. 7.

terms of *moment*, or force multiplied by distance, as foot pounds. The amount of force P necessary to twist the head off the bolt shown in the cut, will depend upon the distance from the axis of the bolt at which the force P (or the couple PP′) is applied to the wrench handle. If it is applied at two feet from the axis, it will take only half as much force as if it is applied at one foot from the axis, but the product of pounds into feet, or "foot pounds," will be the same.

The resistance to torsion of a cylinder of any material, varies as the cube of its diameter. A demonstration of this fact may be found in Wood's "Resistance of Materials," page 208. The following formulas are given:

$$Pa=\tfrac{1}{2}\pi Jr^3, \text{ for brittle materials} \quad (1)$$

$$Pa=\tfrac{2}{3}\pi Jr^3, \text{ for ductile materials} \quad (2)$$

in which P is the force applied at the distance a, the product Pa being the moment, usually expressed in foot pounds, π equals 3.1416, r is the radius of the cylinder, and J the *modulus of torsion*, a quantity which is found by experiment, and varies with each material. Formula (1) is based on the supposition that the resistance of each fiber varies directly as its distance from the center, and formula (2) on the supposition that the resistance of each fiber is the same. Both formulas are deduced mathematically, by processes which may be found in Wood's "Resistance."

In experiments on cylindrical specimens, to obtain merely the torsional strength of a material, the quantity Pa is found, and from the result of the experiment the quantity $\frac{1}{2}\pi J$ (or $\frac{2}{3}\pi J$) is calculated, which is the strength of a piece of one inch radius or two inches diameter. Having this quantity, or modulus, the strength of any cylindrical piece of the same material is found by multiplying the modulus by the cube of the radius.

Prof. R. H. Thurston has recently invented a testing machine which determines the strength, ductility, resilience and homogeneity of materials by torsional strain. A complete description of this machine, with an account of results obtained by it may be found in a paper by the inventor, published in the *Journal of the Franklin Institute* in 1874.* The principal features of the machine which recommend its adoption for general use are, its extreme simplicity

* Van *Nostrand's Magazine*, Vol. XI.

and cheapness, its convenience of operation and its autographic registry. By the latter a strain diagram is made, which shows the resistance of the material at every instant of the test. The value of the graphic method of recording tests has already been shown, in treating of tests by tensile stress, and the automatic graphic record of this machine is especially valuable, as it is more accurate than any plotted diagram.

The autographic record of a torsional test of any material is almost precisely similar to a strain diagram made by plotting the results of a tensile test, as shown in the plate given with the discussion of tensile stress, page 48; but the vertical distances of any point of the curve from the base line represent foot pounds of moment, and the horizontal distances from a vertical line at the origin represent angles of torsion. As in the plotted diagrams the vertical distances indicate strength, the horizontal distances ductility, the inclination of the initial portion of the curve from the vertical is a measure of the coefficient of elasticity, the point at which the curve begins to bend toward the horizontal marks the limit of elasticity, the area included between the curve and the base line measures the work done upon the specimen in breaking it, or the resilience, and the regularity of the curve indicates the homogeneity of the material. The strength expressed in foot pounds of moment, has a direct relation to the tensile strength, varying somewhat with different kind of material, and when this relation is known, the distance of the curve from the base line is a measure of tensile strength with a sufficient approximation to correctness for nearly all practical purposes. The ductility, expressed in the angle of torsion, has a direct relation to the extension of the exterior fibres of the specimen, depending upon the size of the latter, hence the angle of torsion is a measure of extension. It is thus seen that a test by torsional stress of any material can be made to give a record of all the qualities which render it available in construction. This is done by Prof. Thurston's machine with the utmost convenience and accuracy. The writer has made several hundred tests with this machine and can therefore speak from experience. It is now in use in several manufacturing establishments and institutions of learning. A torsion machine, somewhat similar to that of Prof. Thurston, but lacking the feature of automatic registry, has been invented by W. E. Woodbridge, M. D. It was used by the inventor in an extensive series of experiments on steel wire, the results of which, with a plate and description of the machine, are given in a report by him to the government.* The writer is not aware that this machine has been used by other experimenters, but it appears to be well designed, and capable of doing accurate work.

RESISTANCE TO CONTINUED AND TO REPEATED STRESSES, TO SUDDEN SHOCKS AND TO VIBRATIONS.

The preceding discussions have chiefly had relation to the strength of materials as determined by tests of limited duration, and in which the stress is usually applied gradually or without suddenness, and repeated but a few times, if at all.

The conditions to which materials of construction are subjected when in actual use are quite different in some respects to those in which the test specimen is subjected. They have to endure uniform strains through many years, or many centuries, as in buildings; uniform strains with variable strains and sudden shocks at intervals, as in bridges; rapidly recurring strains of different kinds repeated millions of times, as in reciprocating parts of machinery; incessant tremors and vibrations, as in railroad cars; and sometimes every variety and combination of all of these.

As it is manifestly impossible to subject a material to a test which shall fulfill all the conditions of actual use, it is desirable to know what relation exists between the resistance of each variety of material used in construction to steady strain applied for a limited period, to its resistance to continued or repeated stresses, to sudden shocks, and to tremors or vibrations. Thus questions like these may arise: If a rod of iron one inch square in section will resist a steady pull of 50,000 pounds for one hour or one day without breaking, what steady pull will it resist without breaking

* "Report on the Mechanical Properties of Steel, chiefly with reference to Gun Construction on the Woodbridge system." By W. E. Woodbridge, M.D. Appendix F. to the report of the Chief of Ordnance. Washington, 1875.

for a hundred years? What load will it resist for a hundred years if one-half the load is gradually placed on and taken off the rod a certain number of times each day? What load will it resist if applied suddenly? What load will it resist if the suddenly applied load is repeated a number of times, say a million or a billion times? What load will it resist if the load falls a certain number of feet before striking? What load will it resist if this load falls a certain distance a certain number of times? These and a hundred similar questions might be asked concerning this one rod of iron, and the same might be asked of rods of all kinds of material and of all sizes.

The field of inquiry here presented is almost illimitable, but it is an eminently practical one. Materials of construction are used every day which are subjected to just such various conditions as those above mentioned, but the only knowledge we have concerning the resistance of these materials is that derived from tests of small specimens for a limited time, and that derived from observations of materials in use under similar circumstances. On some of these points our knowledge is already definite enough for all practical purposes. Thus it is safe to assume that a stone pillar, resting on a stone foundation, that supports a certain load for one day will support it for a thousand years; if the elements do not destroy the stone; as the pyramids of Egypt and the columns of Greece appear as strong to-day as they were when they were erected. They are living witnesses of the strength of the materials that compose them. The endurance of iron under similar circumstances may be considered still a disputed question. If 50,000 pounds will break a bar in a test taking a limited time, 45,000 pounds may break it if applied long enough, but it may not. It is reasonably certain that there is some weight less than 50,000 pounds which it will sustain indefinitely, but it is also certain that a very much less weight than this will break it if it is repeatedly applied and removed.

Roebling, in his report on the Niagara railroad bridge* states that he found that the iron in the old Monongahela bridge, after thirty years' service was in such good condition that he used it in the new bridge. He also found that the iron in another bridge, over the Allegheny river, was in good condition after forty-one years of service. On the other hand, iron rods used in stiffening the frames of some Ohio river steamboats have been found to break after less than ten years service, and on inspecting the broken rods they were found to be brittle and worthless throughout, although they were of excellent quality when put into the frames.

Resistance to Continued Steady Stress.—The question of the endurance of iron and other materials under steady stress is, as has been stated above, still a disputed one, and the records of experiments bearing upon the subject are somewhat conflicting. The results of the experiments of Vicat, which showed that an iron wire loaded to three fourths of its ultimate strength broke after remaining loaded for thirty-three months, seems to be at variance with the results obtained by later experimenters; which show that iron offers an *increased* resistance to steady stress with time. A full discussion of this subject would extend this paper to an unreasonable length, but the conclusions to which the writer has come, after reviewing a vast amount of the work of recent authorities, may be briefly expressed thus:

Each material has a certain limit of strength (not the initial elastic limit, but usually beyond it) *within which limit it will endure a steady stress indefinitely; but any stress which causes it to pass this limit will, if continued long enough, cause it to rupture.* The exact limit for each material has yet to be determined by experiment, but it is probable that with glass, hard steel, cast iron, and all brittle materials, the limit is but little short of the point of rupture, and that these materials will endure indefinitely a strain which is almost sufficient to cause rupture. With materials like lead, tin, or other soft and ductile materials, it appears that the limit is reached at a stress which is only a small fraction of what they will bear in a test which lasts but a few minutes. Evidence of this has already been given in the remarks upon the influence of time on tensile tests. In these metals, "of an inelastic, viscous character, which do not show an eleva-

* *Journal Franklin Institute*, 1860, Vol. LXX, p. 361.

tion of the elastic limit under strain, and which offer an increased resistance when the rapidity of distortion is increased," there seems to be a *flow of particles* which almost any load will cause, and which almost any load will continue until rupture takes place. They are therefore unsafe metals to use in construction.

With metals like wrought iron and soft steel, Vicat's experiments seem to show that they also exhibit viscosity and flow, and that therefore long continued strain might cause their ultimate rupture; but later experiments, by Prof. Thurston, Commander Beardslee, U.S.N. and others, indicate that, *within certain limits*, no appreciable flow takes place (or if it does take place it soon ceases), but on the contrary that an increase rather than a diminution of strength occurs. This latter phenomena has been named the "elevation of the elastic limit." Still later experiments by Prof. Thurston, however, indicate that both phenomena can be shown by the same material; the elevation of the elastic limit is exhibited in the beginning of the test, or perhaps throughout the test nearly to the end; and later on, flow is exhibited, and rupture finally can take place under a steady and not increasing, or even under a decreasing load. Much light has been thrown upon the subject of endurance of continued strain by experiments made within the last five years, but there yet remains a wide field of research.

Resistance to Repeated Stress.—It is only within the past few years that any really scientific investigation has been made of the resistance of materials to repeated steady stresses. The results of these investigations plainly show that if a piece once resists without breaking any given stress, it is by no means certain that it will resist an indefinite number of repetitions of that stress.

As the result of a long series of experiments for the Prussian government, A. Wöhler, in 1858, first pointed out that a load much less than that necessary to cause rupture by a single application would cause rupture if repeated a sufficient number of times; and that it was not sufficient, in experiments on materials of construction, to learn only the rupturing strength for a single application of load, but that it was necessary, for a safe foundation for calculation, to experiment upon the resistance to stress frequently repeated. The results of his researches are embodied in the following general statement, which is known as Wöhler's law*:

"*Rupture may be caused, not only by a steady load which exceeds the carrying strength, but also by repeated application of stresses, none of which are equal to this carrying strength. The differences of these stresses are measures of the disturbance of continuity, in so far as by their increase the minimum stress which is still necessary for rupture diminishes.*"

Unwin states, in reference to Wohler's researches, that they show that the safety of a structure, subjected to a varying amount of straining action, depends upon the *range of variation* of stress to which the structure is subjected, and on the number of repetitions of the change of load. It has hitherto been assumed that the safety depends only on the maximum intensity of the stress, but this must now be considered to be erroneous. Every machine, subjected to a constant variation of load must be designed to resist a practically infinite number of changes of load. In order that it may do so, the greatest intensity of stress must be less than that for a steady load, and less in some proportion which depends upon the amount of variation the stress undergoes in its successive changes†.

Weyrauch remarks upon Wöhler's law, that in the general form already given it is without doubt correct, and it may even be considered as a *long-known* result of experience, since we continually make unconscious use of it. "If one endeavors to break a beam walled in at the end with the hand, and a single pull proves insufficient, he naturally ceases, and pulls again and again, and when this fails per chance accomplishes the fracture by bending to and fro. The force of the arm is not greater in the second case than in the first, but we do not even need so great a force. We have long known therefore that by alternate stress in opposite directions, where the differences of stress are greatest, the force necessary for rupture is less than for repeated stress in a single direction, and still less than for a single application of such a

* Weyrauch, Strength and Determination of the Dimensions of Structures. New York, 1877.
† Unwin, Elements of Machine Design, London, 1876.

stress. . . . . There remains still much room for the further development of Wohler's law. In his experiments, the stress was repeated very rapidly; the strains however require a certain time in order to reach their full intensity; we disregard now impact proper. What influence has the rapidity of the repetition, what influence the rapidity of the increase of stress, and what the duration of the individual stresses? The questions are not as yet satisfactorily answered."

Wohler found that a bar which is alternately subjected to compression and tension will endure a much smaller number of repetitions of strain than the same bar to an equal amount of tension or compression alone. Certain bars of wrought iron and steel were equally safe to resist varying bending and tensile straining actions repeated for an indefinite time when the maximum and minimum stresses had the following values:

FOR WROUGHT IRON.

In tension only from + 18,713 to + 31 pounds per square inch.

In tension and compression alternately, from + 8317 to − 8317 pounds per square inch.

FOR CAST STEEL.

In tension only from + 34,307 to + 113,436 pounds per square inch.

In tension and compression alternately from + 12475 to − 12475 pounds per square inch. + represents tension, and − compression.

Wohler's experiments have been completely confirmed by those of Spangenberg*. The latter states that numerous experiments confirm Wohler's second deduction, viz: "*Differences* of strains at the extremes of vibrations are a sufficient cause of rupture," and that as the strain increases the *differences* which are sufficient to cause rupture become less. Experiments showed that variations of stress between the following limits may take place with equal security:

Iron	between	+160 Ctr.†	and	−160 Ctr.		per sq. in.
	"	+300 "	"	— 0 "		
	"	+440 "	"	+240 "		

Axle Cast Steel	between	+280 Ctr.	and	−280 Ctr.		per sq. in.
	"	+480 "	"	— 0 "		
	"	+800 "	"	+350 "		

Spring steel not hardened	between	+500 Ctr.	and	0 Ctr.		per sq. in.
	"	+700 "	"	250 "		
	"	+800 "	"	400 "		
	"	+900 "	"	600 "		

and for shearing resistance,

Axle Cast Steel	between	220 Ctr.	and	−220 Ctr.		per sq. in.
	"	380 "	"	0 "		

The following is one of the tables given by Wohler showing the effect of repeated bendings in one direction:

HOMOGENEOUS IRON.

Maximum strain in ctr. per sq. in.		Number of bendings before rupture.
550		169,750
500		420,000
450		481,975
400		1,320,000
360		4,035,400
320	sound after	3,420,000
300	sound after	48,200,000

Unwin remarks: "Unfortunately, Wöhlers experiments, although extensive, do not furnish decisive rules for practical guidance. They afford an explanation of the apparently high factors of safety which in certain cases experience has shown to be necessary, but they are not complete enough to indicate precisely the factor of safety to be chosen in different cases. Nor, indeed, could rules be obtained without the most careful comparison of the results of researches of the kind begun by Wöhler with the actual stresses found to be safe in practice, in a great variety of cases."

For a discussion of the researches of Wöhler and Spangenberg, the reader is referred to Dubois's translation of Weyrauch on "Strength and Determination of Dimensions of Structures." The same work gives formulas derived from the results of Wohler's experiments, by Gerber, Shäffer and Launhardt, for the dimensioning of structures subjected to repeated stresses and to alternation of tension and compression, but the formulas are not yet generally adopted in practice, and the accuracy of the numerical constants which enter into them is doubtful.

The present state of our knowledge upon the subject of resistance to repeated stresses is singularly defective. The

* Spangenberg. The "Fatigue of Metals." Translation: Van Nostrand, New York, 1876.

† A centner=110.2 pounds Avoir. and 1 German square inch = 1.0603 English square inch.

Germans have been the only experimenters in this field (a limited research by Sir William Fairbairn, in England, perhaps alone excepted) and their results, as presented to us in English translations, are so beclouded with discussions of theories that they are not appreciated by the ordinary practical reader, and they have not yet found their way into English or American text-books.

There is scarcely any subject of more importance to the engineering profession. Wohler's investigations are of immense value as far as they go, but they must be supplemented by still more extended investigations before they can be available for general practice. The field is such a large one that it would take a century for private experimenters to explore it. The research can be efficiently made only under the direction or patronage of government.

Resistance to Shock.—Materials are frequently called upon to resist sudden and violent shocks. As a shock is caused by the sudden arrest of a *moving* force or load, it cannot be measured like a steady strain in pounds; but its amount can be expressed in units of work or energy, as foot-pounds, or the product of mass into velocity or of force into space.

The subject of resistance to shock was treated of by the writer in a note published in the *Metallurgical Review* of October, 1877.* The following extracts from that note may be quoted here:

"The resistance to shock is not merely a resistance to an external force, but to force moving through space or to a mass moving with a velocity. It is a resistance to energy, which is measured by the product of the force into the space through which it moves, or by the product of one-half the moving mass which causes the shock into the square of its velocity.

"Also, the resistance to shock is not merely a resisting force, but a resisting force moving through space; a *work* measured by the product of the mean resisting force into the space through which it acts. The space through which the resisting force acts, in tensile strain produced by shock, is the extension.

"If rupture does not take place, equilibrium must exist between the shock-producing energy and the shock-resisting energy, or between the work of the shock and the work of the resistance. Expressed in symbols,

$$FS=\tfrac{1}{2}MV^2=RS',$$

in which F is the force causing the shock and S the space through which the force acts, M the mass of the moving body and V its velocity, R the mean resistance, or resisting force, and S′ the space through which the resistance acts."

The product of the mean resistance of a material to steady strain into its ultimate ductility (or amount of extension or other distortion before rupture) furnishes us an approximate measure of its shock-resisting capacity. This product is termed the "resilience,"* and it is expressed in foot-pounds or other similar unit. In the graphic method of recording results, heretofore described, the resilience is represented by the area of the diagram. This measure, however, is only approximate, as the time occupied in the test may have an influence upon the amount of the resilience. We know that soft metals, such as tin and zinc, show greater resistance to rapid than to slow strain, while their ductility under either rapid or slow strain is the same. The resilience is greater therefore under rapid than under slow strain. If the time is made as short as the endurance of a shock, a small fraction of a second, the resilience may be still greater. With wrought iron and steel probably the reverse is the case, as we know that they offer greater resistance to slow than to rapid distortion—the ductility remaining, as far as we know, nearly constant. The resilience under strain rapid enough to constitute a shock might be much less than the resilience under steady strain. This is apparently indicated by the results of experiments on iron and steel armor plate, the plate cracking or "starring" under the impact of a shot fired with a high velocity, to a much greater degree than would probably happen under the impact of the same number of foot-tons produced by a greater load at a smaller velocity.

Experiments on the resistance of materials to shock are not numerous. In practice, car axles are tested by placing

* Vol. I. p. 190.

* Some writers have used this term to designate elastic range, or "spring."

them on supports at the ends, and dropping a heavy weight on them in the middle. The deflection caused by the blow or by successive blows or the number of blows they will stand without breaking is taken as a measure of their shock-resisting capacity. In the steel works, specimens are frequently tested by blows from a steam hammer, applied in various ways. No experiments, it is believed, have yet been made to determine what precise relation resistance to shock bears to resistance to steady strain and to ductility. As already stated, the product of the two latter affords an approximate measure of the former, but the precise relation probably depends upon the velocity of the shock producing force. The impact, $\frac{1}{2}MV^2$, may be a constant quantity (M and V^2 being variable, but their product constant) but the resistance to impact, RS′, may possibly not be constant, R varying as some function of V.

Resistance to Repeated Shocks.—The single violent shocks treated of above usually occur only in what are called accidents, but in all constructions repeated shocks, tremors or vibrations much less than that sufficient to cause rupture are of constant occurrence; and a knowledge of the resistance of materials to these repeated shocks is a much more important matter than a knowledge of their resistance to a single heavy shock.

Wohler's and Spangenberg's experiments teach us something in regard to the effect of repeated steady strains, but there have been scarcely any experiments on the effect of repeated shocks, and nearly all our information on this subject is the result of common observation and experience. We know that in breaking a piece of cast iron if one blow of a sledge does not accomplish the result, several will. It is well known that pieces of machinery may be in use for years subjected to light shocks repeated millions of times, and will at some time break under a lighter shock than they have repeatedly experienced. Prof. Wood states: If repeated, shocks upon metals are quite certain to produce fracture sooner or later. All metals in use have their life. They can sustain only a certain amount of service."

It is generally believed that repeated shocks will change the mechanical condition of a material, and render it weak; as in the case of iron, by changing the structure from fibrous to crystalline. The evidence upon this subject is, however, conflicting, and direct experiments will have to be made before it can be satisfactorily settled.

Fairbairn says: "We know that in some cases wrought iron subjected to continuous vibration assumes a crystalline structure, and that then the cohesive powers are much deteriorated; but we are ignorant of the causes of this change." In another place he says; "I am inclined to think that we attribute too much influence to percussion and vibration, and neglect more obvious causes which are frequently in operation to produce the change." The fact is, in my opinion, we cannot change a body composed of a fibrous texture to that of a crystalline character by a mechanical process, except only in those cases where percussion is carried to the extent of producing considerable change of temperature.

The late John A. Roebling, in his report on the Niagara Suspension Bridge, in 1860, gives as his opinion that "a molecular change, or so-called *granulation* or *crystallization*, in consequence of vibration or tension, or both combined, has in no instance been satisfactorily proved by demonstration or experiment." This seems to be in direct conflict with the testimony of most authorities, and with a great accumulation of facts learned by common observation.

Prof. Wood, in a review of this subject, remarks: "These several facts, though apparently somewhat conflicting, show quite conclusively, that some metals will crystallize under certain conditions; that under certain conditions they may be strained millions of times without being damaged, or at least without being broken; that under certain conditions strains and shocks combined may produce crystallization; that shocks when severe will weaken metals and, if they are sufficiently numerous, will produce rupture. Much evidently remains to be learned upon this subject."

As already stated, the product of tensile strength and ductility is an approximate measure of the capacity of a material to resist a single heavy shock. We know little or nothing however con-

cerning the relation of strength and ductility to resistance to repeated shocks. It is generally believed that the material which is best able to resist a single heavy shock is also best able to resist a succession of lighter shocks; and this belief is acted on in practice. Thus in certain kinds of machinery pieces which are subjected to innumerable vibrations or light shocks are made of the very finest and most ductile iron or of the softest steel.

Car axles, which are subjected to continuous "hammering" while in service, are made of steel which must be so soft as to resist without breaking one or more blows of a heavy weight falling a number of feet. The percentage of carbon in steel for axles is therefore kept under a certain figure in order that the steel may be soft enough to stand the test without breaking.

It is tolerably certain that the axle which will resist the test of heavy blows without breaking will also not break at the beginning of its service by an accident which causes it a very heavy shock, such as a derailment, but will rather bend; but it is not at all certain that this axle would have a longer "life" in ordinary service than one that is less ductile, and that would be broken under the test by blows. Neither is it certain that the very soft steel used in vibrating pieces of machinery would have as long a life as harder steel used in place of it.

The most valuable contribution to our knowledge upon the subject of the resistance of steel to repeated shocks, is that given by Mr. William Metcalf, in a letter to the *Metallurgical Review* for December, 1877. It is all the more valuable, since it is directly in opposition to the common belief mentioned above, viz: that soft steels are the best adapted to resist repeated shocks and vibrations. The importance of the subject will justify the reprinting here of a brief extract.

"This action of resistance to vibration we first observed at the Crescent Steel Works about three years ago, and it was a complete surprise to us, as up to that time we had always used the mildest steel to resist such strains.

"The piston rods of steam hammers used on steel always break. In hammers where the life of a wrought iron rod was about three months, a mild steel rod was found to last about six months. To improve upon this still milder rods were tried, and four to five months' use obtained, to the surprise of everybody. An accident caused the hurried use of a rod much higher than any ever tried before, probably containing .60 carbon. Immediate provision was made for its replacement by a mild rod, its destruction being expected in a few weeks. The high rod ran over two years, or about four times as long as the average of milder rods.

"The next case was that of steel for small pitmans, where the test required was that a machine should run 4½ hours, at a rate of 1200 revolutions per minute, unloaded, before the pitman broke. These pitmans were unforged in the middle, and consisted of a piece of straight round bar with a head welded on each end, the middle of the piece being left as it came from the rolls. This explanation is necessary in order that it may be understood that no accidents of forging affected the results.

"The first trial was with .53 carbon steel: mean time of six trials, 2 hours 9⅛ minutes. Second trial, .65 carbon steel: mean time of six trials, 2 hours 57½ minutes. Third trial, .85 carbon steel: mean time of three trials, 9 hours 45 minutes, or more than double the requirements. This was satisfactory and the trials were stopped.

"These trial pitmans were all of uniform quality except as to carbon. This led to the trial of a set of twelve pitmans taken from ingots which were carefully analyzed by Prof. J. W. Langley, who published a paper on the results in the *Am. Chemist* of Nov., 1876.

"These pitmans were of a finer quality of steel than the above.

The .30 C. ran 1 h. 21 m. heated and bent before break'g
" .49 " 1 h. 28 m. " " " "
" .53 " 4 h. 57 m. broke without heating.
" .65 " 3 h. 50 m. broke at weld where imperfect.
" .80 " 5 h. 40 m.
" .84 " 18 h.
.87 carbon broke in weld near the end.
.96 " ran 4 h. 55 m. and the machine broke down."

Should Mr. Metcalf's results be found on further experiment to hold good for all kinds of steel it may well be doubted whether the practice of using soft steel for car axles is the best practice, and also whether engineers who have used the softest steels in bridges have used the materials which offers the greatest security to human life. The increasing

use of Bessemer and Siemens-Martin steels in structures and the substitution of these materials for wrought iron renders the subject one of vast importance. A thorough series of experiments on the resistance of the various steels to repeated shocks and on the relation which this resistance bears to tensile strength, ductility and other mechanical properties, and to chemical composition would be of far greater value to the world than the researches of Wöhler and Spängenberg on resistance to repeated steady loads.

It may be well to explain why a knowledge of the relation between resistance to repeated shocks and other mechanical properties is important, as well as a knowledge of the absolute value of this resistance for various materials: Direct experiments on resistance to repeated shock will be somewhat difficult, and they may take a long time to make; while experiments on tensile, compressive or torsional strength, or on ductility may be made at most in a few hours. If then it can once be settled what relation exists between these kinds of strength and ductility and resistance to repeated shock for all materials, it may then be possible to tell with precision from the "strain diagram" furnished by a tensile or torsional test of any material what is the capacity of that material to resist repeated shocks, without subjecting it to direct experiment.

It would be eminently proper that the series of experiments mentioned above should be made either by government or under its patronage; but in view of the increasing use of Bessemer steel in construction, and the immediate necessity existing that we should know something of its ability to resist continued shocks before putting it into structures, and also of the proper kind of steel to be used under different conditions, it seems probable that it would be to the interest of the Bessemer steel companies to make such experiments for their own benefit.*

Conclusion.—All the various forms of stress to which materials can be subjected have been treated of at length, but the subject is by no means exhausted. Much might be said of the effect of different conditions in increasing or decreasing strength. Of these are: influence of temperature of the metal when cast; of mass of casting; of temperature of piece when tested; of amount of work done on piece; of reheating, rerolling and welding; of annealing; of remelting; of compression while in the fluid condition; of cold-rolling; of removing the outside surface; of punching or drilling holes in plates, etc. The influences of these conditions have been discussed by several writers on strength of materials, and it is not necessary to extend this paper further by treating of them here. As a most important practical fact it may be well to state that the process of compressing metal while in the liquid condition has been found to cause a great increase in strength, and it is likely that it will be extensively adopted in the manufacture of steel. The process of cold-rolling has been found to increase the strength of bar iron in some cases as much as 100 per cent.

A table of the strength of various materials might be appended, but such tables already exist in abundance, and the writer would rather discourage, than otherwise, reliance on published figures of strength. In the first portion of this paper several examples were given to show the unreliability of such figures. In all important structures the material to be used should first be tested; there should be no guesswork in regard to the strength of a bridge rod or any piece on which the safety of life may depend.

If the result of these articles shall be to show to manufacturers and users of materials how recklessly and incorrectly tests of these materials have been and are being made, if they shall tend in any degree to bring about some reform in the common method of testing, and if they shall help make more general the belief that no material should be used in an important structure until specimens of it are first subjected to test, their object will be accomplished.

* The writer has recently designed an apparatus for the use of Bessemer steel works and others, for the purpose of testing the relative resistance of different grades and tempers of steel or other metals to long continued and repeated small shocks, by which a number of pieces can be tested at once, and the test of each piece made in a few minutes or in several years as desired. He hopes soon to have such an apparatus built and to publish results obtained from it.

A PROPOSAL is receiving favor for the construction of a railway between Alyth and Braemar in Scotland.

THE GAS ENGINES AT THE PARIS EXHIBITION.

By M. ARMENGAUD. Jr.

Abstract of the Author's Address at the Conference du Trocadéro.

Translated from "Revue Industrielle" for Van Nostrand's Magazine.

The attention of most of those in attendance at this Conference has doubtless been drawn at the Exposition to certain machines, which in their general appearance and mode of working resemble steam engines. But upon approaching them it is readily seen that the similarity is only apparent; the movements of these motors is accompanied by a series of slight detonations, and a near inspection reveals the fact that attached to each is a perforated chamber within which burns a flame which seems to give life to the machine. These are the gas motors. The motive power is derived from illuminating gas and not from steam.

It is proposed to present to the conference some explanations of the structure and mode of working of the different engines of this class exhibited at the Champ de Mars, and to consider the possible future achievements of the inventors and constructors of these engines if they continue the progress so clearly made manifest by this exposition.

Such a programme would hardly seem to possess sufficient interest to hold the attention of an audience not composed exclusively of engineers. But it is proposed to relieve the subject of its technical character as far as possible, and present the more general form of discussion. The task is rendered easy by the very happy circumstance that in the working of a gas engine we find a summary of the most beautiful applications of scientific principles.

A gas motor possesses the essential organs of the steam engine; the cylinder which receives the gaseous fluid; the piston which by aid of rod and crank transmits the pressure to the shaft—the fly-wheel which regulates the motion and the pulleys and belts by which the power is conveyed to the machines to be driven.

The gaseous fluid is a mixture of gas and air in such proportions as is most susceptible of explosion when brought in contact with an ignited body. The mixture is exploded by the little flame before mentioned, and the products of the combustion, suddenly dilated by the heat, urge the piston and develop the motive power. The gas on burning combines with the oxygen of the atmosphere; that is to say, the carbon is converted into carbonic dioxide and the hydrogen into water. This change is completed only under the condition that the volume of air is sufficient to afford the proper amount of oxygen; the gas requires about seven times its volume of air. The combustion may be completed in the open air or in a closed space. An example of the first kind is afforded by the burners in metallurgical works. The gas and air arrive separately and by small quantities at a time, so that their union is effected without sensible noise. If, however, the air and gas are mixed in advance and ignited in a closed space, then the combustion takes place throughout the whole mass at once; a strong detonation and a probable rupture of the envelope immediately follow. Of such a kind are the explosions which result from the careless leaving a gas pipe open in a closed room. The gas diffusing throughout the room becomes capable of exploding as soon as the volume of gas is equal to one-twentieth the volume of the air.

The flame is not absolutely necessary to effect the explosion, as an electric spark will serve the same purpose, but it is necessary to establish a point of intense heat somewhere in the mixture.

The effects of gas explosion are explained, as are those of powder explosions, by the enormous increase of volume of the combustion products at the instant of burning.

In the case of the mixture most suitable for explosion, seven parts of air to one of gas, the explosion develops 10180 units of heat for each kilogram of gas used, or 6000 units for each cubic meter. This heat is instantly communicated to the gaseous products raising their temperature, about 2700 degrees.

Now as gas dilates to the extent of $\frac{1}{273}$ of its volume for each degree of rise of

temperature, it follows that a heat of 2700 degrees would expand the mixture to nearly ten times its normal volume.

When a mixture of twelve parts of air to one of gas is exploded in the cylinder of a gas engine, the heat developed by the explosion is about 1400 degrees, and the gases develop a tension of six atmospheres. The effect on the piston is the same as would be produced by the introduction of a gas or vapor under a pressure of six atmospheres, and exactly as in the case of such vapor do these gaseous products of explosion by their expansion urge the piston of the engine. In this way is the work of gas engines developed.

Gas engines have many points of resemblance to steam and hot air engines. In one as in the others it is the expansion of a gaseous fluid which originates the work of the engine. Whatever the nature of the fluid, its elastic force is employed to move the piston. This fluid then is only an intermediate agent employed to convey heat, and giving up a portion during the process of transportation. The heat which disappears is converted into mechanical work and is the source of power in the motor. This correlation of heat and motion is one of the most beautiful conceptions of modern science.

The essential differences in the various kinds of motors above mentioned reside in the different modes of communicating heat to the intermediate gaseous body.

In steam engines heat is first employed in converting water into steam and then in augmenting the heat of the steam. The vaporization is effected outside of the cylinder, that is to say, in the boiler and some time before the steam acts upon the piston. In hot air engines the heat which dilates the air is equally apart from the cylinder.

It is quite otherwise with gas motors, for in these the heat is developed within the cylinder and in the midst of the gaseous mass and only at the moment that power is wanted. As there is no storing up of the heat nor any transportation of it, these causes of loss are avoided.

The advantages of such a mode of production and utilization of heat are apparent. While in the steam engine, the time of firing up, of evaporating the water, and of raising the steam to a proper temperature is necessarily consumed, in the gas engine it is only required to admit the gaseous mixture by a single turn of the stop-cock. Furthermore, *the gas engine consumes fuel only while it is doing work.* In this quality it possesses a great advantage over other heat engines in those branches of industry which require only an intermittent application of power.

Although the conception of the employment of a detonating mixture as a source of power is a simple one, the practical realization is not without complexities. The heat developed by the explosion of the mixed gases in the old Lenoir gas engine was communicated to the products of the explosion and the excess of air too suddenly; the expansion was too violent and in no way like the motive force in steam or hot air engines. Its ill effects were only mitigated by admitting air in large excess before the explosion. Such sudden shocks were not in keeping with the regular motion required of a motor.

Furthermore, the heat tended to escape as rapidly as it was generated by conduction through the sides of the cylinder. A testing of the cylinder resulted, which was only partly avoided by a current of water on the outside.

The heat developed in the cylinder of the gas engine tends to disappear in two ways: one by conduction through the sides of the cylinder and subsequent radiation; and the other by the expansion of the gaseous products left after combustion. The first of these is useless; the other useful. Utility demands that the first should be counteracted and the second developed. One step towards the accomplishment of this object is attained by allowing a very rapid expansion of the gases in the cylinder. Gas engines ought, therefore, to work with high velocity.

Loss of heat is also occasioned by the escape, from the cylinder, of the mixture at a high temperature. It is clearly necessary furthermore to develop all the heat of which the original combustible gas is susceptible. This is attained by its complete combustion, which depends upon the method of mixing with air and igniting.

Such are the requirements for good service in gas engines. We propose to

explain to what extent they are fulfilled in the gas motors of the Exposition, first glancing at the history of previous experiments in this direction.

As with all other great inventions many nations claim the honor of producing the first gas engine. A very complete and impartial history of the subject has been written by M. H. Tresca, who presides over this Conference. From this history are largely drawn the notes here presented.

The application of gun powder as a motor preceded the use of both steam and gas. Before thinking of the employment of steam, Papin constructed an engine to be driven by cannon powder, following suggestions made by Huyghens in 1678, and Hautefeuille in 1680. In the machine described by Papin in 1688, and which contains a piston and valve, he did not seek to utilize in a direct manner the expansion of the gas, but only the force which is the direct result of this expansion. It was upon the same principle that he devised a little later a steam engine.

John Barber, in 1791, was the first who proposed to produce a motive force by burning hydrogen or other inflammable gas. But his engine was without a piston and was only urged by the force of a jet leading from the vessel in which the explosion was produced.

Then came the inventions of Thomas Mead and Robert Street in 1794, who employed—one the gas resulting from combustion of some substance in a fire, and the other the volatile vapor produced by dropping petroleum or terebenthine or similar substances into the cylinder.

To Philip Lebon, who invented gas illumination, is to be ascribed the honor of devising the principles of construction and working of the gas engine

It is most remarkable that in the machine described by Lebon in his patent of 1799, there are two pumps one for the air supply and the other for the inflammable gas. These imply a certain state of compression before the explosion, an idea which is one of the most salient points of the improved motors of the Exhibition. Lebon also devised the use of the electric spark for igniting the mixture, a method employed in the Lenoir engine.

Experiments by Rivaz in 1807, by Samuel Brown in 1823, and by Talbot in 1840, only need be mentioned here. A patent in this latter year by MM. Demichelis and Monnier describes for the first time the use of gas. It was generated in an apparatus which formed part of the engine. In some patents coal gas was replaced by vapor from petroleum and by other volatile liquids. Other inventors proposed to use air which had been carburetted by passing through naphtha, benzine or similar liquids.

Omitting the names of many experimenters of this period, Hugon (1858). and Lenoir (1859), may be mentioned as being entitled to the honor of first applying gas motors to industrial purposes. These two forms were known and enjoyed celebrity in 1867. Several Hugon engines figured in the French section in the Exposition of that year.

It is unnecessary to describe here the details of these machines. It is sufficient to say that they utilized directly the expansion of the gases. The piston at each stroke admitted on one side the mixture which was ignited at the middle of the stroke, and expelled on the opposite side the products of the combustion. The essential differences of the two systems was in the distribution and mode of igniting the gases. Hugon employed a gas flame for this latter purpose, and Lenoir an electric spark from a Rumkhorff coil.

The Hugon engine is supplied with an apparatus for carefully adjusting the quantities of air and gas supplied to the cylinder; but it does not appear that any advantage in the way of economy of consumption of gas has been gained over that afforded by the Lenoir engine.

Next to these forms came the engine of Otto and Langen of Cologne. This is a vertical engine, the former were horizontal. The principle of action of the Otto engine is different inasmuch as it utilizes the effect of expansion in an indirect manner only.

The piston rod urges the shaft only in an intermittent manner; it is geared to a pinion on the shaft which engages the shaft by means of a friction pulley only on the down stroke. On the up stroke the piston is driven violently by the expansive force of the gases till the pressure of the mixed products equals the atmospheric pressure, and is carried beyond this point by acquired momentum. It

stops only when the work of the atmospheric resistance has absorbed the accumulated work in the piston. There results a rarefaction under the piston, so the down stroke is urged by atmospheric pressure aided by the weight of the piston. This descent is the effective stroke of the engine, for it is only then that the piston rod is connected to the driving shaft.

This method of employing the effects of the explosion only indirectly has yielded good results economically; affording one horse power for a consumption of one cubic meter of gas per hour, in place of 2.7^{m} as in the Lenoir and Hugon engines. But the noise of the engine as in the former cases is quite unendurable, and has led to its rejection.

Claude Segré, an Italian engineer, and M. Schmitz, the engineer of the Paris gas company, have made a thorough study of these systems of motors, and with the result of the following classification into two general divisions.

1st. That system in which the expansive force of the gases acts directly upon the piston and, through this, upon the other moving parts, as in the Lenoir and Hugon engines, and

2. That in which the force of the explosion urges the piston (which for the moment is free) until a partial vacuum is created below it, when the atmospheric pressure is brought to act, and at the return stroke producing the effective work. This includes the Otto and Langen engine.

Sometimes both plans of action are exhibited in the same engine. An example of this kind is afforded by the Gilles motor, a specimen of which was exhibited in the English section of the Exposition. This belongs to an improved form of which there are three kinds, represented respectively by; 1st, the motor of Mr. Otto, of Cologne; 2d, the engine of Louis Simon of Nottingham; and 3d, the engine of M. Bisschof.

In the engines of Messrs. Otto and Simon, the mixture of gas and air is compressed before explosion, so that the initial pressure at the moment of ignition is twelve atmospheres; double that obtained in the Hugon and Lenoir engines where the mixtures before explosion were at a tension of atmospheric pressure only. Furthermore, in these new forms the ignition of the gases is gradual.

The two ideas of previous compression of the mixed gases and a gradual combustion, instead of a violent explosion, distinguish the improved engines from the old forms.

We will describe these systems more particularly:

The Otto engine resembles externally a single acting steam engine. It has a single horizontal cylinder, open at one end and closed at the other, with a head furnished on the inner side with a conical cavity. The piston is connected by a crank with the shaft of the fly-wheel. Behind the cylinder is the supply chamber, which is furnished with a direct connection with the main shaft. The piston at the in-stroke does not reach the end of the cylinder, but leaves a space equal to about two fifths of the capacity of the cylinder. This is the compression chamber.

The cylinder serves the double purpose of compression pump and working cylinder, which is perhaps not the least of the characteristics of the new system.

The complete cycle of motions in the Otto engine is accomplished only by two complete revolutions of the working shaft, or four strokes of the piston. It comprehends the four following phases: viz.

1st. The piston makes an up-stroke drawing in the explosive mixture of gas and air;

2d. The inlet cock closes and the piston returns, compressing the gaseous mixture;

3d. At the moment the down-stroke is completed and while the tension of the gases is somewhat above two atmospheres, the mixture is inflamed and the consequent expansion causes the piston to make an up-stroke;

4th. The piston returns driving out the expanded and cooled gases.

Thus of four strokes of the piston, only one (the third) conveys motive force to the shaft.

The second consumes power; the other two have no appreciable effect.

Such a method of working calls for a heavy fly-wheel, the accumulated work of which accomplishes the compression of the gases.

A special regulator to the engine inter-

cepts the supply of gas and delays the ignition whenever the velocity becomes too great. Furthermore, the engine works without noise—a great advantage over the Otto and Langen motor.

The effective working power of the engine is of course the difference between that afforded by the expansion of the gases and that absorbed by the compression. The indicator diagrams show a regular curve of pressures very different from the line of abrupt changes exhibited by the Lenoir engine.

The regular decrease of pressure in the Otto engine is due to the method of burning the mixed gases. The combustion is retarded so that the heat developed is absorbed by the gases, at a rate that is in better accord with the motion of the piston.

M. Otto has accomplished this by his method of mixing and admitting his gases. He employs two different mixtures; one of fifteen parts air to one of illuminating gas, which he calls his "feebly explosive mixture;" the other of seven parts air to one of gas is called his "strongly explosive mixture."

During the working of the engine, and at the moment when the gases are about to be ignited, the contents of the cylinder are: products of the preceding explosion, atmospheric air, hydrogen and hydro-carbon gases. These are not uniformly diffused, but owing to the position and action of the valves, the most combustible portion is at the bottom of the cylinder at the point of ignition, and the combustibility probably decreases quite regularly from the bottom of the cylinder to the piston.

The result of this condition is a *prolonged* explosion, and the force of expansion is less of the nature of a shock than in the previous engines.

In order to insure combustion with proper rapidity, a jet of "strongly explosive mixture" is made to traverse the mass at the critical moment.

Such is the principle of action of M. Otto's engine. It satisfies the theoretic conditions indicated above. That it employs heat to good advantage is indicated by the small loss shown by the outside cooling of the cylinder. Experiments prove a heating of 35 litres of water per hour for each horse-power, the water being raised from 10° to 85° C.

This is 2,520 units of heat; as 6,000 units are generated by the combustion, the loss is 42 per cent. The loss in the Lenoir engine, according to M. Tresca, was 85 per cent.

The principle of compression was employed in the hot air engines. Ericsson and Franchot both applied it in their motors. In these engines it has a double use: at first, to diminish the temperature to which the air must be raised, and so diminish the heating which is pernicious to these engines, and then also a reduction of the size of the parts of the engine for a given power is accomplished.

But if the previous compression is so advantageous in the working of the engine, it may be asked is it equally advantageous to its practical performance? In other words, is the advantage gained an adequate return for the work expended in compressing the gas?

Calculation shows that the same quantity of gas not compressed would yield a greater amount total of motive force, but on the other hand the loss by compression is compensated by a better utilization of the heat generated.

By means of the measurement of the lost heat mentioned above, it is found that the Otto engine is nearly three times as effective as either the Lenoir or Hugon engine.

It is not surprising therefore that in place of 2.7 metres of gas consumed for each horse-power per hour, the Otto engine yields the same power by the consumption of one cubic metre or probably less in large engines.

The principle of action of the Simon engine is essentially the same as the Otto, but there are some notable differences in the details. The compression is performed in a separate cylinder; upon the admission to the working cylinder the mixture is ignited by a gas flame kept constantly burning. The cylinders are vertical and the two piston rods connect with the same horizontal shaft.

The admission of the explosive mixture and the escape of the products of combustion are managed by valves worked by cams on the working shaft. The mixed gases are admitted in a series of small charges and inflamed successively, thereby insuring a gradual expansion. This method affords also a good

economy of heat, a very small quantity of water sufficing to keep the cylinder cool.

The regular variations of tension in the working cylinder were sufficiently shown by the indicator diagrams taken during the Exhibition. The curve exhibits some slight sudden variations upon the opening of the inlet valve, then it rises to full pressure and remains for a time constant; then falls nearly to atmospheric pressure at the opening of the escape valve. It is claimed that the consumption of gas is less than one cubic metre per horse-power per hour.

One of the peculiarities of M. Simon's plan, is the use of steam in connection with his gaseous mixture.

It was an idea of the earlier inventors —M. Hugon among the first, to reduce the excessive heat in the cylinder by a jet of water. But it proved difficult to regulate. M. Simon introduces a jet of steam from a boiler heated by the escaping gases. The water supplied to the boiler is first used to cool the working cylinder. Thus the heat which tends to escape is utilized. Furthermore, the steam in the cylinder tends to absorb with useful effect any excess of heat resulting from the explosion, and also acts to some extent as a lubricant to the piston.

M. Simon claims to have obtained results superior, in point of economy of working, to those obtained by the Otto engine.

The Bisschof engine belongs to the class that utilize the effects of an explosion to drive the piston. The cylinder is vertical and the piston rod connects with the shaft in such manner as to utilize in the fullest degree the effect of expansion. No water is employed for cooling the cylinder; the result is secured by constructing the cylinder with projecting ribs or flanges so as to expose an abundance of radiating surface.

Engines of small size only have thus far been constructed on Bisschof's system. Most of those made have been designed to run sewing machines with a capacity of $\frac{1}{15}$ to $\frac{1}{2}$ a horse power. The working of these costs, in Paris, two cents an hour for the former, and only five cents for the latter size.

It was the intention of the inventor to solve the question of furnishing a light motor for domestic use. Its advantages are:

1st. It employs no water.

2d. It possesses great stability without specially prepared foundations.

3d. It utilizes as completely as possible the force of the explosion, by the long stroke of the piston.

4th. All shock is avoided by cushioning the air on the down stroke.

The cylinder is heated by a gas burner a few minutes before starting, otherwise the moisture, resulting from the explosion, might deposit within the cylinder and in the absence of oil rust it. By starting with the cylinder heated this is avoided.

The Ravel motor could not be shown at the Exposition under conditions that would permit its working.

In this engine, which is called by the inventor *moteur a centre de gravité variable*, the explosion of the mixture lifts a heavy piston. The cylinder is furnished with trunnions which turn in bearings and which being prolonged form the axis of the machine. An explosion chamber, either attached to the end of the cylinder or independent of it, receives the explosive mixture where it is ignited by a gas flame; the heavy piston is thrown upward; the reaction forces the cylinder to oscillate like a pendulum, and as at each fall of the piston a new explosion gives it a new impulse, the oscillations are continued. The time of fall of the piston is made to agree with the vibration of the cylinder, by varying the resistances to the rise of the piston. No experiments have been tried with this engine which would justify the expression of a definite judgment in regard to its efficiency, though the principle of its action does not forbid the expectation of a good degree of economy.

Having thus reviewed the gas engines of the late Exposition, we arrive readily at the conclusion that the progress in this direction since 1867 has been very great. The improvement, is evidently not alone owing to the ingenious mechanical devices, but also to a closer study of the utilization of heat. The science of thermodynamics teaches us that heat and motion are effects of the same cause; they are equivalent. All loss of heat is loss of work or energy, and, in case of the motors just consider-

ed, the heat produced is a measure of the gas employed and the cost of the motive power.

The expense of working, therefore, depends upon the proper utilization of the heat. This expense has of late been much reduced, the consumption of $2\frac{1}{2}$ cubic meters in the Lenoir engine yielding the same useful effect as is obtained by one cubic meter in the Otto engine.

Some improvement had previously been made it is true in Otto and Langen engines, but it was counterbalanced by such an intolerable noise that their use has been generally abandoned. They are in vogue only in Germany, and are employed there to the astonishment of those people who attribute to our neighbors on the Rhine a more delicate musical ear than ours.

The motors of Otto and Simon exhibit superior qualities in the way of economical working. If at present the Bisschof engine does not possess the same advantage, it still merits a favorable appreciation for having furnished, in so complete a manner, a solution of the problem of supplying a motor of one-man power.

What is more reasonable than to expect of our gas companies a supply of heat and force as well as light? Many light industries which require machinery might then be pursued at the home of the artisan.

But to realize this extension in the application of gas engines, it is necessary that the fuel should be cheaper. If heating quality alone were to be considered, gas could now be afforded at lower cost. A ton of coal yields about 300 cubic meters of illuminating gas, but about double that quantity of combustible gas of good heating quality could be obtained from the same amount of coal.

The question of supplying a cheaper gas for heating purposes, is worth considering by our gas companies, and also whether the same service pipes may not serve the double purpose, furnishing one kind of gas by day and another by night.

In thus eulogizing gas engines, it is not to be concluded that they are recommended to replace steam engines. There is a use for all. Gas motors will compete with small steam engines or with water engines; and in places where neither gas nor water power is easily obtained, hot air engines may properly be preferred.

In concluding this glance at recent progress, the wish may be expressed that this advance towards the amelioration of human toil shall not be checked, but that the end may be soon reached in which all of man's intelligence shall be demanded, and almost nothing of his muscular strength. Although we are yet far from this desideratum this consoling thought remains to us, when from this point of view we compare our epoch with antiquity. In place of the sad inscription "Sale of Slaves" in the market place, we read on modern sign-boards "Motive-power to sell."

REMARKS BY THE PRESIDENT, M. TRESCA.

I ask permission to call attention a little more particularly to two points in the discussion which has been so well presented by M. Armangaud.

If I estimate correctly the old engines of Hugon or Lenoir consuming 2,500 litres per horse-power per hour, would cost, at the present price of gas in Paris, 75 centimes per hour, as one horse-power is 75 kilogrammeters per second, it follows that power at the rate of one kilogrammeter per second costs one centime per hour. If we reckon the work of a man turning a crank at five kilogrammeters, it results from the above estimate that the cost of this labor performed by the gas engines is five centimes per hour.

The later improvements however yield such results that one man-power per hour is afforded for two and a half centimes. But the machines of the Exposition of 1867 yielded as good results as this. There has been no great improvement in economy of consumption in ten years. The problem presented now is to furnish an economical motor whose dimensions are only such as is required for driving light machines, and of which the consumption of fuel shall be in the same proportion as the larger engines.

The gas engine would seem to be dependant upon gas distribution. But a good substitute is afforded by a mixture of volatile vapors with atmospheric air, and the results obtained are nearly or quite equivalent to those from the con sumption of gas.

I add these remarks because the gas engine thus modified is a motor in which

heat is transformed into work in the best possible manner, and I have far more confidence in the future success of these modifications of the gas motor than I have in the hot air engines, which require so much more space and do not conform readily to the theoretic conditions of the problem.

DISCHARGE OF SEWAGE INTO THE SEA.

By HENRY ROBINSON, C. E.

From "Journal of the Society of Arts."

A very general impression prevails that if a town is situated close to the sea it is necessarily in a more advantageous position than inland towns, respecting the disposal of its sewage, as it has only to avail itself of its proximity to the sea to get rid of its sewage by discharging into it. That this is an erroneous impression the experience of most of our watering places proves, and it is therefore desirable to offer a caution to those who are contemplating adopting a similar course. In the Local Government Board Blue-book of 1876, one of the conclusions arrived at is as follows:—"That towns, situate on the sea-coast, or on tidal estuaries, may be allowed to turn sewage into the sea or estuary, below the line of low water, provided no nuisance is caused; and that such mode of getting rid of sewage may be allowed and justified on the score of economy." This has been often quoted as encouraging the adoption of this method of sewage disposal, and it is to be regretted that the report gives no data whatever (such as are abundantly available) by which the qualifying expression, "provided no nuisance is caused," would be shown to apply to a great number, if not the majority of cases. It might have been stated that, to avoid a nuisance, the sewage must be discharged into the sea at a point not only below low water, but where there is a well-ascertained current which would carry it permanently seaward. A point of discharge complying with these conditions is but seldom found to exist close to the town, but has to be reached by long and costly outfall sewers, or rather tunnels. At the outfalls there should be a continuous movement seaward during the twenty-four hours, instead of an oscillating action to and fro, resulting in a return of the sewage and its deposition along the shore, not only at the outfall and in its immediate neighbourhood, but also at distant places to which the tide carries. The writer has had occasion to inspect many watering places where the foreshore is being distinctly polluted in this way. At first the mischief is not great, and only traces of the sewage are visible; but in time it becomes serious, and the knowledge of the existence of sewage pollution on the foreshore causes the place to be avoided by those who hitherto have resorted to it. The grievance is not a merely sentimental one, as the exhalations along the foreshore from sewage accretions at low tide involve not only offensive smells, but also a danger to health.

The difficulties attending the discharge of sewage into the sea would be diminished were it not that it has a higher temperature and a lower specific gravity than sea or river water, which causes it to rise to the surface; and if it is not carried seaward at once, part of the suspended solid impurities are deposited on the coast wherever there is still water and no tidal current, whilst the rest of the suspended, together with the dissolved, impurities float on the surface, and are carried backwards and forwards by every tide, decomposing and liberating gases (sulphuretted hydrogen being one of the most offensive) injurious to health and polluting the air.

In some cases, by means of long outfall sewers, the sewage is carried clear away from the place producing it, as at Brighton. These practically become elongated cesspools, in which noxious gases are generated, and are liable to be forced back into the town drains, and thence into the houses. In these long

outfalls, also, the solids deposit and involve both expense and difficulty to remove. Even if the places producing the sewage really get rid of it in this way, they are frequently simply transferring it to others, a set of the tide carrying it so as to cause mischief and nuisance elsewhere. No better illustration of this can be given than the experience of Margate. The authorities there proposed, after much competition amongst rival engineers, to adopt a scheme by which the sewage was to be discharged into the sea in a bay about a mile and a half eastward of the town, where it turned out that there was practically no current seaward, so that, had the scheme been carried out, the coast there would have been permanently polluted, as the sewage would have risen and dropped with the tide, evolving all kinds of dangerous and offensive gases, which would have effectually driven visitors away, and have depreciated to a serious extent the value of the neighboring property. Ramsgate is in a similar difficulty, and many other places could be cited where it is a matter of serious concern how to deal with the sewage. The authorities are compelled to drain their towns, and the very effort they make to comply with the sanitary requirements of the day appears to involve them in almost greater difficulties. There is only one way safely of dealing with sewage at seaside places where the tidal currents are not clearly favorable, and that is to deodorize the sewage before it is discharged into the sea.

The authorities of Glasgow have had the question of how to get rid of their sewage under consideration for a long while. A Royal Commission investigated this case, and although the result of this was to advise the adoption of a scheme to carry the sewage twenty-seven miles in a tunnel to the sea, at enormous cost, and although this advice was similar to that previously given, the authorities took the matter into their own hands, and appointed a committee of their body, which has recently presented an exceedingly able and interesting report, giving the results of their investigations. The conclusion they arrive at is not to adopt the recommendations to discharge their sewage into the sea, but to discharge it into the River Clyde after it has been purified by chemical treatment.

Where there is a risk of nuisance, either to the place to be drained or to its neighbors (which is equally important), by discharging sewage into the sea, a clarification and deodorization of the sewage can be easily and cheaply effected. No attempt to arrest the solids in catchment tanks can possibly be satisfactory, inasmuch as they only remove a very small portion or the solids, and become huge cesspools, which have to be cleared out at intervals, with a certainty of causing great nuisance. Filtration is also not admissible, as the filters soon get inoperative, and become in addition as great a nuisance as catchment tanks. By deodorizing the sewage the first difficulty is overcome, as the sewage is no longer offensive.

There has hitherto been much prejudice against chemical treatment, which is, however, disappearing, as it has been abundantly proved that sewage can thereby be deprived of its offensive properties by simple and inexpensive means. The disposal of the semi-fluid sludge has been a difficulty which the writer has had to give much attention to, and he has employed several methods of converting it into a portable form. The plan which he has found the best is to remove a great part of the moisture from the sludge by means of a simple filter press. A model of this press (which is an automatic modification of an old construction of press) has been placed in the Exhibition of Sanitary Appliances. By an appliance of this kind, the sludge has the bulk of its water pressed out, and the consequent reduction both in mass and consistency enables the sludge to be better removed and utilized, or dealt with in any other way.

An amusing result has followed an exhibition of gas apparatus at Wolverhampton. Some of the exhibitors decline to accept the medals awarded them for the very adequate reason that the judges were utterly incompetent. In one case a medal was awarded to a stove which could not even be entered in the class, and which, as a matter of fact, was not even in the exhibition at the time the award was made. One of the jurors did not know what was meant by a Bunsen burner! And yet the public buy in blind faith in medals.

THE SANITATION OF WORKSHOPS.

From "Iron."

At the late Sanitary Congress at Stafford, an address on Workshop Sanitation was read by Dr. J. T. Arlidge, which, though its object was to treat alone of the sanitary conditions and regulations at work where pottery is made, contained so many observations and suggestions of interest to all classes of workshop owners and employers that we think its reproduction here will be profitable. The following is the text:—

Among the hygienic conditions and surroundings of various manufactures, experience and observation have convinced me that we must make a distinction between those inseparable from, and those only incidental to, the manufacturing processes themselves, and that for the greater number of occupations and operating more energetically as factors in inducing disease, the latter play the more important part. This statement, in other words, amounts to this—that with regard to the multiform occupations pursued in this country, the nature of the occupations is undeservedly blamed, in the case of the majority of them, for the ill consequences to the health of those engaged in them. Now I propose in this paper to deal with a manufacture in which the essential conditions and surroundings are really fraught with danger to health; nevertheless, I shall be able to show that the non-essential or accidental surroundings are accountable for very much. To guard myself against misunderstanding, however, I need remark that the line between essential and non-essential conditions of manufacture cannot, in all particulars, be distinctly drawn; and that, in more or fewer of them, some will overlap others.

For example, take the case of dust, which is the most prolific agent in inducing disease amongst potters, we may fairly regard it as inseparable from the processes of the trade, because the material cannot be handled in accordance with the necessities of trade without giving off fine dust; yet, on the other hand, the amount of dust thrown off may be lessened by care, attention and cleanliness, and, further, may be dispersed and driven away by efficient ventilation. Still, notwithstanding this inability to accurately separate the essential from the non-essential conditions of manufacture, I regard it as important and practically most valuable to make the attempt; and firstly, let me briefly sketch the conditions or surroundings of the pottery manufacture, which are non-essential, accidental, or outside the calling, but yet are answerable for more or less sickness, suffering and death amongst those engaged in it. Of this whole class of morbific agencies I may predicate that they are preventable. I do not assert that practically they can all be removed and annihilated, but that we possess known remedies against them capable of being more or less efficiently applied.

The first in order I shall name is defective construction of workshops. In respect of this matter the manufacturers in the Potteries suffer, as do also those in other places, whatsoever be the occupation carried on, by the sins of their forefathers. They inherit old buildings erected ere sanitation had made good its existence. Their demolition and reconstruction is an affair representing capital expended and the tendency is to "make them do" until better days dawn, or progressive dilapidation enforces destruction. Now, a fairly diligent inspection of the buildings used for the making of china and earthenware—or, to use the comprehensive term of the district, of the banks—will reveal too many shops or workplaces wretchedly built, at times in bad repair, with wet dirty floors, damp walls, low ceilings, scarcely high enough for a tall man to stand under, full of draughts, yet not ventilated, and with every trade appliance or fitting covered with a coating of dust of variable thickness. If these be the features of but a few, there are more to be found which, though less unfit as places of labor, are yet far from being what they ought to be.

Defective elevation of rooms, and in its train draughts and bad ventilation are far too generally found. Another common structural defect is the absence of

a plaster ceiling in workshops having others over them, and, as a consequence, the precipitation of dust from the upper floor to that beneath it. Another prevailing structural defect is to be found in the unpaved yards, and in the absence of waterspouts and drains to conduct rain-water away into the sewers. The consequence is wretchedly sloppy and muddy courts and approaches, and concurrently wet feet and drabbled dresses, and the accessories—colds, coughs and rheumatism. Again, efficient ventilation is a thing far too widely neglected in pottery workshops, particularly when considered in connection with the prevalence of dust, pervading especially those shops in which the clay is thrown, moulded, or turned, or in which scouring and dipping of the ware are carried on. The position, the size and the construction of the windows as to the mode of opening and closing them, are such as to make ventilation difficult, or even almost impossible. Add to these impediments to ventilation the frequent mode of warming by what are called pot-stoves, which, standing about the middle of the rooms, heat and unduly dry the air around them by their highly-heated or even red-hot iron surface, whilst causing at the same time very little atmospheric movement upwards through the small iron chimney flue, and yet ever and anon dispersing into the apartment an inconvenient supply of smoke. It is no new thing to condemn these pot-stoves as insanitary; but, for my part, I am almost equally disposed to condemn their modern innovators, the hot-water and steam-pipes, which have found their way into several recently erected factories. For this system of warming, when adopted, as too frequently happens, without corresponding arrangements for ventilating, is but a system of enervating the work-people submitted to it, and provocative of evils as great, perhaps, as that of the cold it is used to guard against. Indeed, I maintain that it is better for a man at active employment to do without artificial warmth from a heating apparatus of the sort in question. The mischief to contend against is the separation of the heating from the ventilating process. When the former is attained apart from the latter, or the latter is let shift for itself, the air of the apartment soon becomes insufferable, doors and windows are opened, and draughts and colds follow, and inflict their injurious consequences upon people peculiarly sensitive to them by reason of the heated, almost motionless, air previously surrounding them. So far as concerns the pottery hands, it must be admitted they are difficult to deal with in this matter of ventilation. They have a morbid dread of cold air, and are unluckily in large numbers the victims of chest affections. As a consequence, they are prone to stuff up ventilators, to cover over any sort of apertures by which the outer air is to be admitted into the room, and to deliver themselves up to a warm, stagnant, effete air laden with particles of dust. That man would be a public benefactor who could invent a simple plan for ventilating and warming the workrooms of potters, and persuade them at the same time to give it a fair trial. Overcrowding of shops is a further insanitary condition not essential to any process in the manufacture of pottery. According to my observation, it is likewise a widely spread one; but I trust that the better defined sanitary requirements of the new Factory and Workshop Act will gradually diminish this evil.

In the manufacture of pottery the use of machinery has heretofore found little application. It is now slowly making its way; but for its adoption to any large extent it will be necessary to replace old factories by new ones, the arrangement and relative situation of the shops of most old factories rendering the adaptation of machinery impracticable or else too costly. The use of machinery would exert a beneficial influence upon the health aspects of the manufacture. The introduction of presses for preparing the clay, in place of the old process of evaporation and plunging, by men exposed constantly to an atmosphere of steam, and to the influx of cold air at the same time from the half-enclosed shed in which the work was carried on, is a movement in favor of the health of potters. So, again, is the adoption of the pug-mill, to replace in great measure, or wholly, the process of wedging the clay. I can point to other examples, in the use of steam to turn the jiggers, the turners' lathes, and the thrower's wheel; and I could well wish to see the like mechanical

agency more widely patronized; for my experience as infirmary physician has shwon me, in numerous instances, the injurious results to health of girls and young women employed in lathe and wheel turning.

Not actually pertaining to machinery, yet allied to it, are the arrangements now pretty generally used in substitution of the old "hot closets," in and out of which boys were kept continually running, with great detriment to health, from the excessive heat and ever-recurrent exposure to chills. These improvements in machinery and in mechanical appliances must be seen to be understood. I will now pass to another set of conditions unfavorable to health, for which neither the manufacturing processes nor the structural defects of the factories are to blame. I allude to the habits, the food and the clothing of the workpeople. But to sufficiently discuss these matters would carry me far beyond the limits of a paper like the present. Let me say, in brief, that there is very far too much indulgence in intoxicating drinks, irregularity in living, indifference and carelessness in the selection and preparation of food, neglect of cleanliness, pride and folly in dress. I do not say these defects are peculiar to potters. I fear they prevail generally among factory hands as a class; but I fancy they are, as a whole, more productive of disease among potters than among other artisans, because by their association with concurrent causes of sickness found in the occupation itself, their power to do mischief is enhanced. For instance, the most fertile source of disease is the dust of potteries, and the morbid resultant affections of the lungs, wherefore the indulgence in alcoholic drinks, which load the vessels and lungs with carbonaceous matter, and otherwise prejudice the respiratory act, prepares the way and facilitates the action of the active morbific agent, the inhaled dust.

I will now turn to the conditions essential to the occupation of potters, or if not positively essential, at least practically inseparable at present from it. The first to be noted is dust. This is evolved from the materials used in the manufacture of pottery; the china and blue clays, the stone and the powdered flint. It is a mineral dust, and extremely fine, consisting mainly of silicious particles. It enters the air-passages, and finds its way into the bronchial tubes, great and small, where, as a direct irritant, it sets up a slow, inflammatory action, ending in altered pulmonary tissue—so altered by condensation and other changes as to be useless for the purpose of respiration. This dust is apparent in the air, and is seen covering all objects in the workshops as well as the clothing of the potters themselves. Some processes are more dusty than others, but none of them in which the clay is worked up into the forms desired are free from it. In the finishing departments of painting, gilding and burnishing, the clay is transformed into china and earthenware, and no dust consequently come from it. We have, therefore, an obvious and direct cause of disease existent in the dust given off from the yet unbaked clay, and its evolution to some extent appears inevitable. As a matter of course, it is used in a moist or plastic condition; but its surface rapidly dries, and readily breaks down into a fine powder on touching, as shown by its soiling the hands. In some processes, particularly in that of turning, the lathe separates fine shavings from the surface of the vessels, still in the "green" state, and with them more or less of the clay in fine particles and in powder. The disposition of the surface to dry and form a pulverulent film is increased by the heat of the work-rooms. Therefore, for preventive measures, we must seek such as will lessen the heat of shops, and the formation on the surface of the unbaked ware of a dry, powdery film, and withal such ventilation as shall disperse the dust generated, and expel it from the work-rooms. Airy, well ventilated, and comparatively cool shops constitute the primary hygienic requirements in the manufacture of pottery. Subsidiary to these are plans for laying the dust by sprinkling the floor, the observance of all means of cleanliness, both of the shops and the persons employed; but it is painful to add that these minor measures to remove a patent cause of disease are greatly neglected. I would throw it out suggestively how far it might be possible to remove the dust from the atmosphere by employing from time to time forcible jets of steam. These we may imagine would induce the precipitation of much dust and lessen the dry heat of the air.

China-scouring has been especially singled out as most noxious to those engaged in it, by reason of the dust generated and the pecularly irritating quality of that silicious dust. It is an occupation of women, and consists in scouring the flinty dust from the surface of the china cups and other articles. It is very provocative of lung disease, although not in the terrible ratio some have reported. The mode in which the work is carried on seems certainly to place it within the scope of remedial measures. These must be in plans for withdrawing the dust from the workers as they sit at the bench with the ware before them, and it seems to me very feasible to effect this by having a perforated bench allowing the dust to fall through, or rather to be forcibly drawn through into an inclosed trough or cylinder below, in which a constant process of exhaustion of the air is effected by the rapid revolution of a fan at its open end, driven by machinery. The perforated bench and subjacent trough have been adopted, but the withdrawing force relied upon has been the suction power of a heated chimney with which the trough has been connected. But this plan is better in theory than in practice. The chimney has not a constant and equal draught, and if the shop become heated when the chimney is cool, the current will be reversed, and no dust will be extracted through the perforations.

Another expedient preventive of the ill consequences of dust inhalation is the use of respirators worn over the mouth and nose. There can be doubt of their efficiency in sifting the dust from the air before it enters the respiratory passages, but the difficulty is to get the workpeople to use them. There is on their part a recklessness and an indifference to consequences; the respirators increase the effort to breathe, and they feel hot and uncomfortable. But what is more fatal to their adoption is, they are innovations on the usages of trade, and, above all, they subject their wearers to the jibes and jeers of their fellow workers, and no class of people are more sensitive to jests, or have so little moral courage in regard to the introduction of novelties as factory workmen and workwomen. In very many factories the evils of dust might be reduced by the re-arrangement of shops and of the several branches of labor. As said before, some branches are more dusty than others, and it is not uncommon to carry on two or more branches in the same workplace, so that all therein employed are exposed to the whole of the disadvantages of processes which otherwise would be restricted to a few.

But, besides dust, there are other conditions of labor inherent in it. For instance, the position taken during work is unfavorable to the normal action of the chest walls. This happens to throwers and pressers. In the handle-making branch there is rapidly repeated pressure upon the lower part of the chest; and in all the finishing processes the position in sitting is more or less constrained. On the other hand, in the case of lathe treaders, there is undue fatigue in standing and in the exertion, by a sort of perpetual jumping on one foot, of treading the footboard or treadle.

There is yet one more department of pottery labor destructive of health which I must mention in order to give my paper any semblance of completeness. It is the department of dipping. In order to put the impervious glaze on the ware after firing in the biscuit-oven, it is dipped into a mixture of lead and borax, combined with other materials, which have previously been all fused together into a vitreous substance, then ground down into fine powder, and mixed with water. The lead of the glaze is, of course, a poisonous ingredient, and, as a consequence, those engaged in dipping the ware are the subjects of severe colic and of paralysis in various and often very aggravated forms. Could lead be eliminated from the glaze one great source of disease of the potter's craft would be abolished. I am told that the proportion of lead used is not so great as formerly, and that an increased quantity of borax may be substituted for the poisonous metal. Whether this be so or not is a question for chemists, and it would be a happy day could these scientific gentlemen contrive a new form of glaze of non-poisonous quality. Probably some lead is absorbed by the skin of the dippers, whose hands and arms are, practically speaking, immersed in the glaze during the period they are at work. But my impression is that the lead finds its way into their sys-

tem chiefly in the form of dust inhaled by the mouth and nose. The glaze most rapidly dries on the absorbent surface of the ware, whilst the clothes of the worker become bespattered with it, and every surrounding object betokens the formation and presence of dust. Here, again, the like remedial measures claim attention as in the case of dust from clay. There is need of airy shops and good ventilation, and, above all, of cleanliness of person and of surroundings. Most manufacturers supply their dippers with means of washing, with towels, soap and nail-brushes, and the Factory Act forbids the partaking of meals in dipping houses. In fact, preventive measures are of the first importance in this department. If experience indicates that some individuals are much more liable to be affected by the lead poison than others, it proves even more forcibly that by care and cleanliness on the part of the men its ill effects may be largely obviated. The use of medicines calculated to eliminate the poison is well known to the workmen, and another excellent means of preserving their health is at their command in the way of hot water, vapor, and Turkish baths. Respirators would serve them a good turn, but, as with other pottery artisans, their prejudices stand in the way of their use.

I have now made a rough survey of the principal un-hygienic conditions of the pottery manufacture. The general lesson to be derived from it is that those conditions are largely remediable and preventable; that one group has most to do with structural and mechanical expedients to remedy it, and that the other is largely bound up with the willingness of the workpeople themselves to lessen and remove them.

APPARATUS FOR ILLUSTRATING THE ACTION OF LOADS UPON TRUSSES.

By R. FLETCHER, Thayer Professor of Civil Engineering, Dartmouth College.

Written for Van Nostrand's Magazine.

In a course of engineering instruction, doubtless some educators have felt the need of a simple apparatus for illustrating the principles of transmission of stress in trusses. A rigid model of any kind has only a very narrow range of utility. A flexible model, representing only a single form of truss, has greater value but is still insufficient, owing to the number of typical forms in use, each involving one or more distinctive features.

Whatever opinions may be held as to the necessity of using models for purposes of instruction, few would deny the advantages of an apparatus combining the following features:

1. Joints so made as to secure perfect flexibility, excepting unavoidable sliding friction,—thus according with the usual hypothesis upon which computations are based.

2. Concentration of weight at the joints, in accordance with another convenient assumption,—the weights representing either "fixed load" alone or both "fixed" and "moving load" combined.

3. Tension members so made and connected as to be incapable of transmitting any compression, and compression members incapable of transmitting tension.

4. Members interchangeable and capable of being combined so as to form different trusses of several of the various types constructed upon the principle of pin-connections.

5. An arrangement by which some form of dynamometer may be inserted in place of any member, and the previously computed stress on such part verified.

Models of a single form of truss, made flexible and having a dynamometer which may be inserted for verification of strain, are already in use in one or more engineering schools. But, so far as the writer is aware, there is nothing of very general adaptation according fully with the above conditions. To meet all of these requirements the writer has recently

devised an apparatus, which appears to have sufficient novelty and utility to justify the following brief description.

The first condition is realized by a form of joint so clearly shown in Fig. 1 as to need little additional explanation.

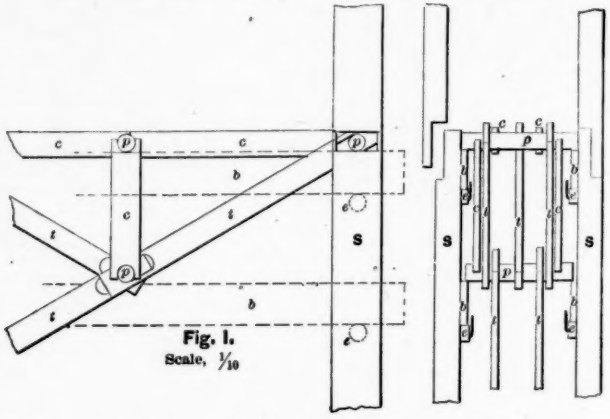


Fig. 1.
Scale, 1/10

The pins, *p*, are made of brass tubing filled with lead. They are six inches long, one inch in diameter and weigh 1.18 lbs. each. Their weight aids very considerably in securing conformity with the second condition. It is almost needless to remind the reader that a model is strained by its own weight only in very small proportion to the strain due to gravity upon the actual structure which the model represents. Assuming for an approximation that the strength of material varies directly as the cross-section, then, if the model were constructed to a scale of $\frac{1}{12}$ the relative weights of model and structure are nearly as $1 : (12)^3 = 1 : 1728$. But the sections of corresponding parts are as $1 : (12)^2 = 1 : 144$; hence, if W is the weight of the model, the weight to be put upon it so as to strain it to the same extent that the actual structure is strained by its own weight is

$$W \times 1728 \div 144 - W = 12W - W.$$

Similarly for any other scale of construction, using the cube and square of the ratio. Accordingly it might be desirable to make the weight of the pins sufficient to bring about this proper proportion of stress. In the case before us, however, such exact relation was hardly practicable with the scale adopted and materials used, without employing too much weight. Pendant weights of lead, of five and three pounds each were made to be hung from the pins or any other part of the frame so as to increase the strains as much as might be required.

The method of meeting the third requirement is shown in Fig. 2. Pieces of

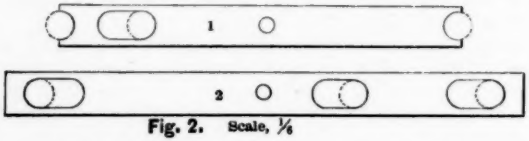


Fig. 2. Scale, 1/6

the form marked 1 simply rest upon or against the pins by virtue of the compressive stress which they transmit.

They cannot oppose any resistance to an effort to further separate the pins. Pieces of the form marked 2 can transmit, evidently, only tensile stress which would tend to increase the distance between the pins; they cannot oppose the slightest resistance to any compressive effort which would crowd the pins towards each other along the lines of the pieces. Compression members should be colored so as to be clearly distinguished

from tension members when in place. By this means much is added to the effectiveness of any combination for illustration.

The fourth condition is fulfilled by carefully proportioning the pieces so that some or all of those used for one combination may constitute parts of one or more other combinations. Some of these other combinations may require a few special pieces not needed elsewhere. The same piece may do service in two or more combinations by having one or more openings at proper intervals for the pins of that combination, as shown in Fig. 2. It is hardly necessary to remark that the planning of the pieces as to dimensions, adjustment of distances from center to center of pin openings, etc., for so many different forms, requires great care, and the workmanship must be of the best, in order to secure accurate fitting of all the parts. The mechanic who makes the pieces should work from carefully prepared drawings of the parts, on a large scale.

It is immediately obvious that such combinations can illustrate nothing as to practical details of construction, but simply the principles of transmission of stress, which is the sole object in view.

Fig. 1 represents the elevation and end view of a part of a Fink truss combination and one support; *p*, the pins; *c*, compression members, which are supposed to be colored; *t* tension members; S one end support consisting of two uprights resting upon a common foot-frame; in this case the uprights are seven inches apart, transversely. The supporting pins at the ends may have to be longer than the others, and there is no need that they should be so heavy. The different parts of the frame must be in duplicate, as seen in the end view, else no symmetrical arrangement in reference to a median plane could be made, and couples would result, destroying equilibrium.

The figure also shows the arrangement for assembling the parts. Strips of thin board, *b*, rest upon buttons, *e*, which are placed against the inner faces of the posts. Each button turns eccentrically upon a wire axis which is prolonged and bent upwards, as shown in the end view, so as to prevent the strip from slipping off. The buttons are so disposed that, when they are turned upwards the strips will have their upper edges exactly on such a level as to just support the pins of the particular form to be assembled. A pair of strips is needed for each chord of parallel-chord trusses, and no more than the four would be necessary for any of the more important forms. The pins being properly placed on the strips, the parts may be rapidly put in position. To aid in placing the end supports at the proper distance apart for a given combination, suitable marks may be made upon the strips. The best disposition of parts for any one combination having been found, it is well to have this indicated by a clear diagram to be kept with the apparatus and serve as a guide for all future assembling of the same form; otherwise there may be frequent confusion and vexation from not remembering the best arrangement of the parts. In some cases a certain order is especially necessary in order to avoid interference of pieces with each other. After the pieces are all in place, the buttons, *e*, are turned half way around, when the strips are lowered a distance equal to double the eccentricity of the buttons, and they may then be removed, leaving the truss supported only by means of the end pins. The illustration represents a "deck" or under-grade truss. For over-grade trusses the posts are continued upwards above the supporting pins and buttons, *e*, are suitably disposed for all the combinations of this kind which are desired. The upper parts of the posts may be made detachable as shown in the end view, and thus put out of the way when not required.

To secure greater stiffness transversely it is well to have a $\frac{3}{4}$ inch hole exactly in the middle of each piece, as shown in Fig. 2. Snugly fitting wooden or metal pins may be inserted after the assembling and passed through each two opposite pieces, thus forming connected pairs throughout the combination. This feature is not indicated in Fig. 1, in order to avoid complexity.

The fifth requirement calls for a dynamometer of special construction. It must be sensitive enough to indicate small differences of strain and yet not be too much extended by the greatest strain it may have to transmit when in place in the truss. It would be desirable, al-

though by no means necessary, to have one capable of indicating both tension and compression. In this particular case the utmost limit of extension, in order not to have too much yielding of the truss under strain was fixed at $\frac{3}{4}$ of an inch, but the actual extension is generally less than half an inch. The form adopted is that of the ordinary "spring balance" with a dial face, the spring being especially made to meet the above conditions. It indicates tension only. The cylinder in which the spring works and the rod which draws the spring, each has a cross-head at the end. Upon each of the latter a pair of eye-bars is secured, the eye-openings fitting the pins of the combination. To adjust for the different lengths of various positions in the same or different combinations, the eye-bars have square holes at carefully ascertained intervals, which fit square ends of the cross-heads. In this case the distance from center to center of pin-openings may be varied from eight to eighteen and a half inches. It may be objected that the yielding of the dynamometer, and consequent distortion of the truss, will make the strains different from those computed for the perfect form. But proper allowance may be made for this—the exact strains being quickly computed by the graphical method,—or the effect may be neglected and the approximate indication taken as sufficient.

The combinations possible with the apparatus thus described are the following:

I and II. The ordinary queen-post truss erect and inverted. With either of these the distortion of a partially braced truss may be shown, and the different effects of bracing by struts or ties. This form is 24 inches long and 8 inches high. These and the following dimensions are from center to center of extreme pins.

III. A Fink truss of four bays, erect. Length 56 inches, depth, 16. Some of the advantages of the Fink system may be strikingly illustrated by this frame.

IV. The same form inverted. This may be inclined at any desirable angle to illustrate its use for roofing purposes, by having a properly arranged bearing on a vertical wall for one end, and rods which retain the bearing pin at the other, or lower end, and hook into staples in the same wall. By this may be shown, also, the effect of changes of load in altering the character of the stress in certain parts.

V. An eight-panel, parallel-chord truss of the Pratt or Whipple type, length 64 inches, depth 14 inches. By this all the principles of counterbracing may be fully illustrated, using few or many counters and distributing or concentrating load to exhibit the action in all cases usually considered, the model showing immediate distortion when insufficiently braced. The dynamometer affords means of illustrating the principles concerning maximum and minimum stress or web members and chords.

VI. The same form inverted. A comparison of any of the inverted with the corresponding erect forms will exhibit clearly the greater stability of those having the lower position of the center of gravity.

VII. A triangular or Warren truss of four panels; length 64½ inches, depth 14 inches. This will illustrate the peculiarities of the system. One piece of each type (1 & 2, Fig. 2) must be inserted where a member is liable to take both kinds of stress, in order to have constant equilibrium. The differences between this and the quadrangular or panel system become so obvious as to need no further comment from the instructor.

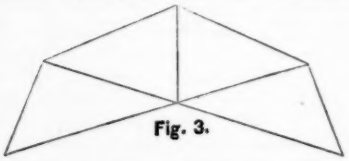


Fig. 3.

VIII. A roof truss of the form shown by Fig. 3; span 30 inches, height 17. This will illustrate the effect of wind pressure on one side in changing the nature of strains due to weight alone in certain pieces on the opposite side.

By having a few extra pieces, the following combinations may be added to the above, if deemed desirable: Howe truss, erect and inverted; triangular truss with vertical suspension members; common king-post truss, erect and inverted. Others might be included also, but there is no advantage in having a great number of forms, since a few is amply sufficient for illustration of leading principles.

Much more might be given in detail,

and other applications described, but the above, which is offered more by way of suggestion than a complete elucidation of that which is capable of further extension and improvement, is sufficient for the interested reader.

THE CONSTRUCTION OF CONVEYOR SPIRALS.

By S. W. ROBINSON, Professor of Mechanical Engineering, Ohio State University.

Written for VAN NOSTRAND'S MAGAZINE.

CONVEYOR SPIRALS may be made in various ways: of cast iron, wrought iron, or wood, separately or combined, and with one or more wings. The object of the present paper is to give some simple rules for making the wings of sheet metal, such as shall be adapted for attachment to a wooden core or spindle, and when thus attached, to stand, at each element, exactly radial. Such wings will be truly helicoidal, and of the form that would be generated by a line kept constantly perpendicular to the axis of the helicoid, and moved along it with a constant velocity and with a constant rate of rotation.

Spiral wings of such form will be warped surfaces, and evidently cannot be formed from flat sheet metal without swaging. For instance, suppose a helicoid be made of a flat strip without any core, and with the axis in the middle of the strip. By hammering the edges from the middle line out, and not the middle line, the edges will become puckered and forced into some twisted shape like an ordinary auger bit. By careful management, a true helicoid is obtained. It is evident that the amount of stretch required increases on each side with the distance from the axis. It is easily seen from this, that if an annular sector, or bent strip, had been taken in place of the straight one, it might have been made helicoidal by stretching the edges and not the middle in a similar manner, resulting in such a helicoidal wing as would fit upon a core.

The rules we seek are, therefore, such as give the proper curvature of the annular sector and the proper stretch for the edges of it for a given case.

RADIUS OF THE ANNULAR STRIP.

Let the annular strip be represented by the figure ABFH, the circular edges being struck from the center O. AB is the radial width of the spiral wing, and AE the radius of the core of conveyor, or spindle upon which the wings are mounted.

Let the annular segment be so shaped that a narrow portion of it lying along the concentric circle line CI will neither need swaging nor bending edgewise.

Let S = the length of any truly helicoidal line which makes one complete turn; r, its radius; and P, its pitch.

Then

$$S^2=P^2+4\pi^2r^2,$$

as can be seen by supposing the spiral developed by unrolling the circumscribing cylinder upon a plane.

Any other spiral line of the same pitch will also give,

$$S_1^2=P^2+4\pi^2r_1^2.$$

Subtracting one from the other, member by member, and

$$s^2-s_1^2=4\pi^2(r^2-r_1^2)$$

or

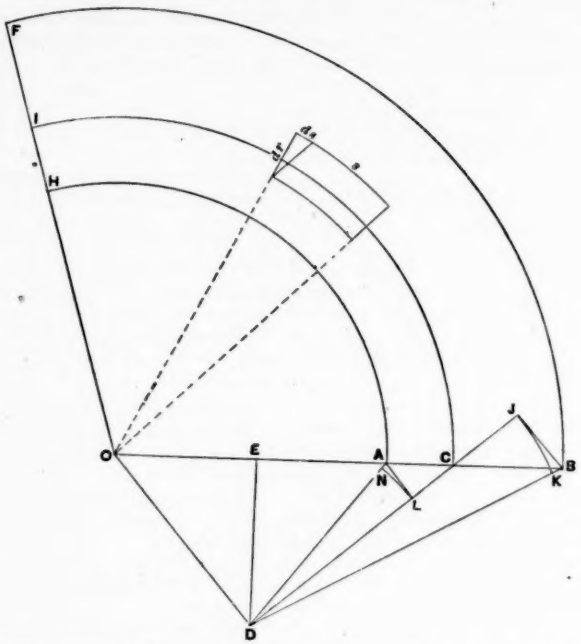
$$(s-s_1)(s+s_1)=4\pi^2(r-r_1)(r+r_1).$$

If the spirals are taken with only a small difference dr, in the radii, we have $r-r_1=dr$ and $r+r_1=$ sensibly $2r$ and at the same time $s-s_1=ds$ and $s+s_1=2s$ ∴

$$sds=4\pi^2rdr.$$

The same result would have been obtained by differentiating the first equation above.

Let these two spirals be supposed to lie very near to the line CI. The space between them may be regarded as that above mentioned, which is not hammered nor bent, but simply twisted. It is a sort of neutral element to the spiral wing. A small portion of it is shown in the figure, from which we see, observing that s and ds vary together, we have,



$$ds : dr :: s : CO.$$

Combining this with the last equation, we get

$$CO = r + \frac{P^2}{4\pi^2 r}$$

But r=CE, according to what precedes, and hence

$$CO - CE = EO = \frac{P^2}{4\pi^2 . CE}$$

from which EO may be computed, as soon as the point C is assumed. If it is taken at the middle of AB, the inside edge, AH, will require much more stretching than BF, as will appear below.

We may obtain the point O graphically by drawing a perpendicular ED, making

$$ED = \frac{P}{2\pi},$$

and then drawing CD and DO, right angled at D. This is proved from the fact that this construction gives

$$CE : ED :: ED : EO.$$

$$\text{or } EO = \frac{\overline{ED}^2}{CE} = \frac{P^2}{4\pi^2 . CE}$$

as required. Hence O is determined.

THE LENGTH CI FOR A COMPLETE TURN.

The first equation gives the length for a complete turn

$$s = \sqrt{P^2 + 4\pi^2 r^2} = 2\pi \sqrt{\frac{P^2}{4\pi^2} + r^2}$$

The first term under the last radical is $\overline{ED}^2$, and the last term is $\overline{CE}^2$. Then the radical equal CD, and $2\pi \times CD$=a circle described with CD as a radius.

Hence the length, CI, if the annular sector sufficient for a complete turn, is the circumference described with the radius CD.

THE AMOUNT OF SWAGING.

The edges must be lengthened to change the flat to a warped surface. To simply change the length of the edges and not the width of piece, a hammer with a wedge shaped pene may be used with the line of the pene crosswise of piece. But even this will increase the width slightly, and for this reason the piece may be cut out a little narrow. A ball pene will require still greater allowence for expanding width.

To form a particular spiral, a definite

amount of saving is necessary, which amount must be known in order to shape the wing without a pattern.

To determine the amount of stretch to be given to the edges by the hammering, we see from the first equation above, that the final length of AH for a complete turn will be,

$$S=\sqrt{P^2+4\pi^2\overline{AE}^2}=2\pi\sqrt{\frac{P^2}{4\pi^2}+\overline{AE}^2}$$
$$=2\pi.AD.$$

And the length before stretching will be,

$$AH=CI.\frac{AO}{CO}=\frac{AO}{CO}.2\pi.CD$$

and the stretch will be,

$$S-AH=2\pi\left(AD-CD\frac{AO}{CO}\right)$$

By drawing AL perpendicular to CD, or parallel to DO, we have from similar triangles,

$$DL : CD : : AO : CO.$$

$$\therefore DL=CD\frac{AO}{CO}$$

the same as the second term in the parenthesis for the value of stretch. Hence,

$$AD-CD\frac{AO}{CO}=AD-DL,$$

or,

$$=AD-DN$$

if a circular arc LN be struck from a center D.

Hence, the stretch required for the side AH, of a piece AF just sufficient for a complete turn is,

$$S-AH=2\pi(AD-DN)=2\pi.A.N.$$

or equal the circumference of a circle struck with the radius AN.

For pieces AF of a length to make a fractional part of a turn, of course, a corresponding fractional part of the circumference to AN will be necessary for the stretch.

In a similar way it may be shown that the stretch for the outside edge BF will be,

$$2\pi.BK$$

where BJD = a right angle, and DK = DJ.

As regards the choice of the point C, nothing appears above to indicate that it is limited in position. In choosing it near A will throw most of the hammering upon the outer edge, and *vice versa*. A little inquiry will naturally lead to selecting that point which will result in giving the same stretch per inch to the two edges AH, and BF. This will make the total stretch of AH to BF, as AO is to BO, because AH : BF : : AO : BO. Now if CD be drawn so as to bisect the angle ADB, the little triangles, or spandrels, ALN and BJK will be similar, and

AD : BD : : AL : BJ : : AN : BK : : AC : BC

: : AO : BO : : AH : BF, since DO is parallel to AL and BJ.

Hence for the same stretch per inch along AH and BF let BC bisect the angle ADB.

The percentage of the stretch will be obtained by dividing AH by the circumference to radius AN, or since AH = circumference to AD, the percentage will be $\frac{AN}{AD}=\frac{BK}{BD}$ for the case of bisected angle ADB.

RULE.

Hence the following rule may be stated for laying out and forming from sheet metal, the wings for conveyors. Referring to the figure:

Make AE = radius of core,

" AB = radial width of wing or blade,

" DE = pitch divided by 2π, and perpendicular to AO,

" DC = bisect the angle ADB,

" DO = perpendicular to DC.

" O = center of arcs for edges AH and BF of piece,

" CI = neutral line, $=2\pi.CD$, for complete turn,

" $\frac{AN}{AD}$ = stretch per unit for each edge, $=\frac{BK}{BD}$.

SANITARY SCIENCE.

A SKETCH BY ROBERT RAWLINSON, C. B.

From "The Builder."

Sanitary science includes works and arrangements necessary to comfort and health—the individual must be cared for. History, for the main part, however, records the deeds and misdeeds of emperors and kings, but the condition of the people is most fully recorded in descriptions of epidemics, pestilence and famine, aggravated by negligence of sanitary science, as also by war.

The strength of a nation has hitherto been estimated by the numerical force of armies and their power to destroy; but sanitary science, when fully understood and reduced to practice, will reverse the order as above enumerated, and the history of the future will take most note of the condition of the people, and the strength of nations will be estimated by a standard of health and intelligence rather than by numbers of armed men compelled to live unproductive lives at the cost of civilians.

Sanitary works must be useful generally; and, to be so to the fullest, they must be simple in construction and in their arrangements. Supervision must also be ample, economical, and unceasing.

The prime works for aggregated populations will be main-sewering, house-draining, scavenging, and a safe and proper disposal of excretal and of scavenged refuse, with a full and pure water-supply, and with public lighting. Villages and isolated houses must be sewered, drained, and have a supply of pure water.

Arterial drainage, the conserving of rivers, and land-drainage come within the scope of sanitary science.

Road and street surface formations are most important works to facilitate general and local traffic, and must be provided.

Having stated these general requirements, it may be instructive to describe briefly some of the great sanitary works of former times; as also some of the existing sanitary works in Great Britain, on the Continent, and in other parts of the world.

Main Sewering and Draining.—Main sewers and drains were constructed in some of the cities of antiquity, and some public buildings were drained, but we have no evidences, written or in buried ruins, that can warrant conclusions that any city of antiquity was completely sewered, including house-draining. There is no evidence that land-draining, in detail, was ever practised by any nation of antiquity, as is now considered necessary by British agriculturists.

Water-supply.—There is abundant evidence, both in history and in ruins, that works of water-supply were executed. Springs of water were utilized, wells were dug, natural lakes were made available, and streams and rivers were led by artificial canals contouring the intervening country. Reservoirs, bunds, and tanks of vast area and capacity were constructed, from which water was drawn for domestic purposes, but chiefly for land irrigation.

There are ruins of aqueducts of great age, especially in India and in Italy—the principal ruins in Italy being those near Rome. There is no reason to conclude that the laws of hydraulics were not understood in early times, as water placed under pressure would rise to its head. The metals lead, silver and gold were used for pipes and valves, in baths, and in the formation of fountains, as also for jets; the use of iron upon a great scale for main conduits and service-pipes is undoubtedly modern. The Romans, however, used lead for main-pipe conduits, necessarily limited in diameter and capacity to suit the strength of the metal.

Pipes of earthenware, moulded on a block by hand, or raised on a potter's wheel, were also made and used at an early period for water-conduits to supply towns, baths, and fountains; in some cases earthenware pipes were bedded in hydraulic lime concrete, so as to enable them to resist pressure, and to be used for street mains, as also to be used as inverted syphons to cross valleys.

Rome, and some cities of Rome, were supplied with water in vast volume, distributed to public and private baths, as

also to public and private fountains; but there is no written record, or other evidence, proving that a domestic supply of water by separate and special service was ever given to the masses of the people.* Main roads were formed by the Romans in Italy, as also in the great Roman provinces, streets were also paved in the great Roman cities, but we have no evidence that at any period highways, roads, and streets were general and were formed and paved as perfectly as those which at present exist throughout the several countries of Great Britain, France, parts of some other Continental nations, and in some North American towns.

Improvements in sanitary science are, for the most part, modern, and up to this date (1878) have had exceptional application. In British India roads, railways, and canals have been formed. Calcutta, and some other Indian cities, have been partially sewered, and works of water-supply have been executed for Calcutta, for Bombay, for Nagpore, and for some other Indian cities. In the Australian colonies works for water-supply have been executed, and main sewerage works are at this time under consideration. There has been considerable movement on the Continent of Europe in main sewering and in water-supply; as also, in Great Britain; but in few towns have sanitary works been fully completed; probably not in any one are sanitary works, sanitary appliances, and supervision as complete as these might be and ought to be.

Complete sanitary works, appliances, and supervision should provide as under:—

For Towns.—The sewering and removal of subsoil-water so as to dry the basements of houses; main sewering of the town and draining of the houses, with a daily disposal of excretal and scavenged refuse, so that there shall not be any removable cause of nuisance. There must also be the formation of good roads in the city and in the suburbs, with the paving of all street and yard surfaces, in such manner, and with such material, as shall best prevent accumulation of dirt, diminish noise, and admit of cleansing by washing. Public lighting must be ample and general, as proper lighting is useful for police purposes.

The main sewers of a town should be of such dimensions, and be laid at such gradients, as will transmit sewage evenly and regularly at rates not in any case less than one mile per hour. The sewers should also be fully ventilated, and have at command ample flushing power. In all main and tributary sewers side-junctions for house-drains should be provided in the first construction, and all houses should be drained, but the drains should not traverse house basements. Water-closets and sinks should be against external walls, and should have means for lighting and ventilation from the open air. Cesspools and cesspits should be abolished. If a drain must traverse a basement from front to back, as in London and in other street houses, such drain must be absolutely air and water tight, and be fully ventilated externally, both front and back. Cast-iron pipes will be safest to use for such drains beneath basements. Back draining is, however, the true mode of sewering and draining streets of houses.

Water-Supply.—A town supply of water should provide for each house and each tenement, having a separate service-pipe and tap within the walls, the service to be high-pressure and constant; a volume equal to fifteen gallons per head of a population, with sound service-pipes and taps, efficiently supervised and maintained in repair, will be equal to the requirements of ordinary populations for all purposes, public and private.

Great mistakes have been made in the design and construction of sanitary works which it may be useful to indicate. As previously stated, the science is new, and some men who attempt to practice it have not learned the alphabet, not having had time, opportunity, or inclination. About 1850 three of the principal English engineers were required by the corporation of the city of London to advise and report upon the best forms and cross-sectional dimensions adapted for main sewering. In their report flat bottoms to sewers are recommended, as being the easiest to cleanse by hand labor, and, according to the rules laid down by these eminent men, no main sewer was to be constructed which was not of suf-

*The volume of water brought into London per day is about 110 millions of gallons. It is recorded that the twenty aqueducts which supplied Rome poured in 300 millions of gallons per day, or nearly the dry-weather flow of the river Thames over Teddington weir. Ancient authors are not, however, always to be relied upon.

ficient dimensions to allow men to enter. House-drains were not to be less in diameter than 12 inches. This report was accepted by English and by European engineers generally, hence the tunnel and canal-like sewers of Paris and of Brussels, executed for small sections of these cities at vast cost in proportion to the areas sewered. Many of the first formed sewers in London were large and flat-bottomed; scores of miles of such sewers remain to this day. The late John Roe and John Phillips first worked out the problem of egg-shaped sewers, with side-entrances and flushing chambers.

Since the year 1850, when I first introduced small sewers, laid at right lines from point to point, with side-entrances, manholes or lamp-holes at each change of line or gradient, as also at junctions of sewers, many entire towns have been so sewered by thousands of miles of small sewers and drains, laid on the principles above indicated. The first town so sewered was Alnwick, in Northumberland, under the supervision of Hugh M'Kie, C. E., the present most able city engineer for Carlisle.

Defective sanitary works may be illustrated by Paris, which may be taken as an example of a city laid out above ground on a most magnificent scale. The main streets are in right lines, open and well paved; the houses are regular in their architecture, lofty, and being built of white stone, are clean-looking and imposing. Paris may therefore be termed the finest-looking city in Europe. Street scavenging and watering are also admirable; but there are many sanitary sores in Paris; as, notwithstanding its big and costly sewers, it is a city of cesspools which are emptied at intervals, carts, or iron tanks on wheels having been specially contrived for this purpose. The covers of these huge cesspools are to be seen at the surface in the newest and most architecturally imposing streets.

The supply of water to Paris is abundant in volume, and is used profusely for public purposes; as in grand cascades and fountains, road-watering and street channel washing; but in quality the water is very hard, being to some people absolutely painful to wash in; the distribution within the house and tenement is not general. The true use of water is to supply, at high pressure, every house and tenement to the entire abolition of hand-carriage; and the true use of sewers is to remove all waste water and all human excreta at once, whilst unfermenting, to some outlet or outlets to be pumped and applied to land. At present there are the labor and cost of all the separate pumping from cesspools in detail, after putridity has set it, and the removal by horse-power of tanks and refuse which in the aggregate involves far more cost and power than dealing with the sewage if delivered at outlets by a full system of main sewers and house-drains, as water flowing down a conduit finds the necessary power to do so in gravity.

London is an example of a vast city, sewered almost in its entirety, the houses being drained also into the sewers; cesspools and common privies having been abolished, though not all filled up, water-closets being the rule. Taking the entire population at some three and a half millions of inhabitants, there is one water-closet to about every five persons; or, there are about 700,000 water-closets in London, soil-pans which are used as water-closets being included.

The water supply of London is also most abundant, and is far softer and consequently purer than the water supplied to Paris. It is true that in London there are no vast cascades or grand fountains, neither are the streets so well watered and washed, nor the street channels so fully flushed and washed, as in Paris; but the city at large is vastly better sewered, has water at high pressure, which is taken within and to the top of the best class houses, and is delivered within the tenement, or near the door of the poorest inhabitant. There are no large recognized cesspools in use, cesspool refuse carts, nor water-carriers. There are, however, defects both in sewering, in house-draining, and in water-supply in London, the result of defective information and divided jurisdictions. Parish vestrydom is not an apt learner: the local governing system is old, the form of election is old, and the ideas and prejudices are old. London has not been improved, laid out, and reconstructed under imperial authority, but has grown up under Dogberry blundering and speculative building, house-draining being the builders' work, the parish authorities having, and very

improperly, only extracted a fee for each drain entering a sewer, without taking the responsibility of seeing that each house-drain did properly join and enter the sewer as paid for, the results being no junctions in some cases, bad junctions in many cases, and no house-drain ventilation in most cases. The street-sewers are ventilated, but not house-drains as a rule. There are many miles of old flat-bottomed, broken-sided, shallow, and defective sewers in some of the richest London parishes—sewers which accumulate refuse and require to be hand-cleansed; but there are also very many miles of well-formed sound sewers, which, by the ordinary flow or by flushing, transmit sewage through the new intercepting and low level sewers to be poured wholesale in the crude state into the Thames at Barking and Crossness, the solids so scoured along, and in suspension, amounting to many thousands of tons per annum. Taking the ascertained results of some towns where the solids of sewage are intercepted, the volume and weight of silt and sludge annually washed into the Thames must amount to 200,000 tons or more.

Modern sanitary works have in some respects disappointed expectation, as reductions in local death rates do not appear to have followed closely upon the expenditure of money and the execution of works; but it is probably overlooked that sanitary works of the most perfect design and execution, with the best regulations fully carried out, do not in themselves solve all the problems of human health. There are the wretched houses, hovels, and tenements of the poor in every town and village of Great Britain, so frequently described by the editor of the *Builder*, in which excessive overcrowding takes place, and out of which inevitably proceed pauperism, crime, and disease. Sanitary science does very little to improve these dens of foul air and misery, unless it entirely supersedes them by new and better dwellings, and the old cottages are improved off the face of the earth, and this is both a costly and a slow progress; then there are spirit and beer drinking, tobacco smoking and chewing, with defective feeding and want of proper clothing amongst the poor, and want of sense to clothe properly amongst the rich, to make up the sum of human neglect and human misery. When these things have been studied, learned, and considered, wonder at continued excess of disease will diminish.

As the strength of a nation is in the health of the people, it must be the duty of governments to see that means of health are secured to every child born into the world. There is no value apart from human life, and there is no form of property so valuable as human life, and as the poor cannot provide their own dwelling-places, and as experience from the first dawn of history proves that defective tenements produce disease in excess, it must be a prime duty of a government so to legislate, order, and regulate, that health shall be possible within the cottage.

The inhabitants of a city cannot, however, all be treated as are criminals in jails; consequently, the health attainable in a model prison is at present exceptional; but sanitary works, properly supervised, can prevent raging epidemics by removing the soil in which the disease, seed, or germ, fructifies. Typhus fever, cholera, and other zymotic diseases, may decimate a filthy, drunken, demoralized population, and yet never enter the county model prison. The black-death, plague, and sweating-sickness of Mediæval Europe appear no more in England, but haunt the foul cities of Asia, and yellow fever now rages in the foul southern cities of America, teaching a lesson terrible to study, but instructive to learn.

The report of the committee of the British Association, on the best means of developing light from coal gas, is largely occupied by a tabulated series of results obtained with different kinds of burners, such as the rat-tail, union or fish tail, bat-wing and argand, and also the influence of globes of different sizes, shapes and materials. The report is strongly in favor of cannel rather than common gas, on account of its comparatively small influence on the atmosphere of apartments and the smaller proportion of sulphur it contains. The report also advocates the burning of gas at a comparatively low pressure, and the use of district governors to equalize the pressure in different levels of towns, and of regulators in houses and street lamps, to give the exact pressure calculated to give the best photometric results.

PROCESSES FOR DETERMINING THE ORGANIC PURITY OF POTABLE WATER.

By Dr. TIDY.*

From "Iron."

The processes for estimating the organic matter in water naturally divide themselves under two great heads. (1) Where the organic matter is estimated from a water residue; (2) where it is estimated in the original water, *i. e.*, from the water itself and not from the residue after evaporation. It is here to be remarked that if it be possible, by any process or processes, to estimate the organic matter in the original water, such processes must have manifest advantages over those where the quantity of organic matter is deduced from a residue.

The Ignition Process.—The first in respect of date, last in respect of value. This process to be of value presupposes three things. First, that no organic matter is lost and none gained during the evaporation of the water. In this point the process fails, because there may be both a loss of the actual organic matter present in the water during evaporation; such loss being either physical, particles being carried off mechanically with the steam, or chemical, from decomposition; and again, resulting from the introduction of extraneous organic matter in the shape of impurities floating in the laboratory atmosphere. Secondly, That all the organic matter is burnt off by the ignition of the residue; and thirdly, that nothing but organic matter is lost by ignition. With regard to both these points the ignition process also fails. The process is not quite abandoned, else there would be no need to refer to it; some analyses having been, not long ago, put in evidence where the loss on incineration was entirely relied on as the indication of organic purity or impurity.

Combustion Process of Drs. Frankland and Armstrong.—The objections to this process are twofold. First, general, and secondly, special. The general objection is its impracticability, arising from the manipulative skill required, and the length of time consumed in conducting the process. These two latter objections may seem to have some weight at first sight, but very little on further consideration. It is admitted that a certain amount of manipulative skill is required, but the possession, by practice, of this manipulative skill constitutes a man an analytical chemist; and the sooner so delicate and difficult a work as water analysis is taken out of the hands of those who imagine themselves professional chemists after a few lessons in a laboratory, the better for chemistry and sanitary science. As regards the time required, rapidity ought not to enter into the calculation if accuracy or delicacy be thereby imperilled. This objection of impracticability is therefore worthless. The question of evaporation is then reviewed, including the ingenious devices of Professor Bischof and Dr. Mills. Until we have definite evidence that no organic matter is oxidized, and also that no organic matter is volatilized or destroyed by the heat required in evaporation, it follows that evaporation must always constitute a possible source of error in any process where the determination is made on the residue. Indeed, we cannot resist the conclusion being forced upon us that after all our trouble we may be simply estimating the harmless organic matter, that which was poisonous and disease-producing having been carefully got rid of by our previous work. The next difficulty, the addition of the solution of sulphurous acid, is an important one. From a careful series of observations the author concludes that if the nitrogen present as nitrates does not exceed 1 part in 100,000, or 3.15 gramme of nitric acid per gallon, the reduction of the nitrates is complete on boiling with 10 or 20 cc. of the sulphurous acid solution. If, however, the quantity present amounts to 1.5 per 100,000, some difficulty was experienced in effecting complete reduction, even when 60 cc. of sulphurous acid solution were used. The next step is the combustion of the residue, the deter-

* Chemical Society, Dec. 5, 1878.

mination of organic carbon, and is quite accurate; but the same value does not attach to the determinations of the organic nitrogen, and therefore it is doubtful how far we are justified in drawing conclusions as to the source of the organic matter, *i. e.*, whether it is vegetable or animal, from the proportion which exists between the organic carbon and nitrogen. However, the process has so much improved on acquaintance that the author believes it to be of great value.

The processes where the organic matter is estimated from the water before evaporation are two: The Ammonia Process and the Oxygen Process. *The Ammonia Process* consists of the comparative determination of the nitrogenous organic matter by the quantity of ammonia (albuminoid ammonia) yielded by the destruction of the organic matter; this destruction is effected by boiling the water in the presence of potassic permanganate and a large excess of caustic potash. Waters are divided by the authors of this process into three classes: Waters of extraordinary organic purity, yielding 0.000 to 0.5 part per million of albuminoid ammonia; safe waters, yielding 0.5 to 0.10; and dirty waters, yielding more than 0.10. The objections made to the process by Dr. Frankland are, that the conversion of the nitrogen of the organic matter into ammonia is seldom or never complete, and that the proportion of nitrogen converted into ammonia in a series of nitrogenized bodies varies widely. There is a certain force in these objections. If the organic matter of all water was alike, it would be of no importance whether the whole or a definite part of the nitrogen was converted; but inasmuch as in all probability the organic matter of one water is not the organic matter of other waters, the circumstance that bodies yield their nitrogen as albumenoid ammonia in vastly different proportions constitutes an objection of some importance. Nevertheless, this objection can be overrated; if it can be shown that the ammonia process indicates clearly that the yield of albuminoid ammonia keeps pace with the purity or impurity of waters, and that it is sufficiently delicate to indicate the finer grades of purity, the fact that piperin yields all its nitrogen, whilst thein yields one-fourth, is of little significance in water analysis, whatever interest such facts possess for the scientific chemist. It must be remembered that Mr. Wanklyn has repeatedly and distinctly condemned the course taken by certain chemists in regarding the process as a method for the quantitative determination of nitrogen, and asserts that his process only answers the question: Is this water wholesome or is it not? whilst it leaves untouched the question: How much organic nitrogen does this water contain? The author proceeds to notice some practical difficulties in the details of the process. It is practically impossible to prepare the alkaline solution of potassic permanganate absolutely free from ammonia, and it is always necessary to estimate the quantity of ammonia in the permanganate solution and deduct this from the total amount obtained in the actual experiment. It is a matter of extreme difficulty to effect the complete (*i. e.*, as complete as the alkaline permanganate solution is capable of effecting) decomposition of the organic matter by boiling the water with the permanganate solution. Thus, you distil a water with permanganate until ammonia ceases to be evolved, and then leave the apparatus carefully protected from contamination for a few hours; on redistilling, a second yield of ammonia, often equal or even larger than the first, is obtained; and so, again and again, fresh quantities of albuminoid ammonia may be obtained until every drop of water in the retort has been distilled over. This is a serious difficulty, and has, in one case at least, led one analyst to report a water to be of "extraordinary organic purity," whilst a second classes the same water as a "dirty water" and entirely unfit to drink. Sometimes, too, ammonia seems to disappear. Thus, the permanganate solution is known to yield a certain quantity of ammonia on distillation. It is added to a water, and the two distilled, when the distillate from the water, plus the permanganate, contains less ammonia than the distillate from the permanganate alone. As regards Neslerizing, a serious error may creep in from the fact that eyes are very far from being equally sensitive in observing and in classifying tints. Thus, out of a large number of average men observing, 60 per cent. failed to arrange a series of Nesler test

solutions in the proper order of their tints. The presence of free ammonia, within certain limits, the author regards as of little importance, and entirely disagrees with Mr. Wanklyn when he regards the presence of more than 0.08 part of ammonia per million as evidence that ammonia proceeds from the fermentation of urea. As a general conclusion from a wide experience, the author thinks that the ammonia process gives fairly concordant results when uniformly conducted, *i. e.*, given solutions made by the same person, the same hands to manipulate, the same eyes to judge of the tint-depths. But this is almost a fatal objection to its general employness; for, if the author's statements be true, in the ammonia process every man must be a law unto himself, whilst one man's law is no one else's law. Hence comparisons are rendered impossible. As a rule, the albuminoid-ammonia process enables you to say whether a water be of excellent quality or of an exceptionally bad quality; but in those more delicate and difficult cases where a water is not what may be termed excellent, but, nevertheless, is not "dirty," in the opinion of the author the ammonia process absolutely and entirely fails.

The Oxygen Process.—This process, when properly carried out, is much relied on by the author. He deprecates most strongly the ordinary method of using it. The proper plan of using the permanganate is the following: Into two 20-oz. flasks, cleaned by rinsing with sulphuric acid, and then thorough washing under the tap, place 500 septems (1 septem = 7 grains = $\frac{1}{1000}$th gallon) of the water, add to each 20 septems of dilute (1 in 3) sulphuric acid and 20 septems of the permanganate solution (2 grains in 1000 septems). Note the exact time at which the permanganate solution was added; at the same time two similar quantities of distilled water are to be treated in precisely the same manner. At the end of one hour and of three hours the oxygen used up by the water is to be determined. To the flasks, after standing the appointed time, add a sufficiency of potassic iodide (1 in 10), and then a standard solution of sodic hyposulphite (5.4 grains in 1000 septems) until the whole of the free iodine is removed, judging of the exact spot by the addition, towards the end of the experiment, of a few drops of starch solution. By deducting the quantity of oxygen equivalent to the hypo-solution used from that in the quantity of permanganate originally added, we obtain the quantity of oxygen used by the water. The blank experiments with distilled water give the value of the hypo-solution. It is obvious the samples of water must have a pink tint at the end of the one hour or the three hours, otherwise fresh experiments must be made with larger doses of permanganate. The author then proceeds to consider the interference of various substances with the process. He concludes that the only important errors which can arise would be due to the presence of ferrous salts, sulphuretted hydrogen and nitrites. The presence of the first two substances would be sure to be discovered in the analysis, and by taste or smell; the nitrites act immediately on the permanganate solution, and any decolorization taking place during the first five minutes must be due to nitrites and allowed for. Besides, even if a careless manipulator was to miss the iron, the sulphuretted hydrogen and the nitrites, and estimate the whole as oxidizable organic matter, he would simply condemn a good water, but could never, by using the oxygen process, pass a bad water as harmless. It is admitted that permanganate fails to oxidize some substances, such as urea; but, nevertheless, the quantity of oxygen used affords evidence of the relative quantity of matter in the water which is likely to be injurious, and this is what we want in water analysis, as it enables us to speak with confidence as to the use or rejection of a water for drinking purposes. The quantity of oxygen used during the first hour, as compared with that used in the first three hours, gives valuable information as to the relative quantities of putrescent, easily oxidizable matter, and of non-putrescent and less easily oxidizable matters. The author also recommends, as a valuable accessory, the tint of the water as seen viewed through a 2-feet tube 2 inches in diameter, daylight reflected from a white card being used. This tube is of special value in determining whether a water is peaty or not. In some cases the tint gives a clue to the quantity of organic matter present. The author has collected and plotted out in curves the results obtained by Dr. Frankland using the combustion process, and

these obtained by Dr. Letheby and himself using the oxygen process, and those obtained with the ammonia process, with the waters of the eight London companies, since 1870. He finds that the curves of the oxygen and combustion processes are strikingly concordant, whilst that of the ammonia process agrees with neither. The author has also divided these results into classes, making, as far as possible, classes (with the three methods of estimating the organic matter) which should be comparable with each other. Thus, Class I. contains waters of great organic purity, which require less than 0.05 parts of oxygen per 100,000 to oxidize their organic matter, or which give less than 0.1 part per 100,000 of organic carbon and nitrogen, or which yield less than 0.05 parts per 1,000,000 of albuminoid ammonia. Compared in this way, out of 1686 experiments, the oxygen and combustion processes tell the same tale in 1418 cases, and of the rest a large proportion have differences depending on the third decimal place. The results by the ammonia process correspond, save in a very general way, neither with those of the oxygen process nor with those obtained by the combustion process. The author has analyzed, moreover, 200 miscellaneous waters, using the three processes in each case. Of these, 94 were placed in the first class by the oxygen, and 92 by the combustion process, whilst only 42 were placed in the first class by the ammonia process. It must be understood that the author deprecates most strongly the judging of a water by one constituent without reference to its complete analysis and natural history, and has only instituted these classes for the sake of comparing results. The relative value of the three processes may be briefly summed up as follows. The Ammonia Process furnishes results which are marked by singular inconstancy, and are not delicate enough to allow the recognition and classification of the finer grades of purity or impurity. The errors incidental to the process form an array of difficulties which become infinitely serious, seeing that the range (from 0.05 to 0.1 parts per million) between pure and dirty waters is comparatively small. The Combustion Process has all the evils of evaporation to encounter, but the organic carbon estimation is trustworthy; the organic nitrogen determination, however, scarcely yields absolutely trustworthy evidence on which to found an opinion as to the probable source of the organic matter.

The Oxygen Process avoids the errors incidental to evaporation; its results are constant and extremely delicate, it draws a sharp line between putrescent and probably pernicious, and the non-putrescent and probably harmless, organic matter. By it a bad water would never be passed as good. As far as the three processes are concerned, the oxygen and combustion processes give closely concordant results, whilst those yielded by the ammonia process are often at direct variance with both.

AMERICAN IRONMONGERY.

From "The Engineer."

Our correspondents in the Sheffield and Birmingham districts have often referred to the competition experienced by the manufacturers in their districts with the cheaper productions of American manufacturers and factors. For the evidence of that competition we need not now go to our producing districts. We find it in every ironmonger's shop in town and country, and particularly in furnishing ironmongery stores. If we ask for locks, gas standards, roller-blind fittings, small brackets, hooks and hat pegs, domestic apparatus and tools, substantial toys, and very many other things, we are shown American productions. The reason for this is not sufficiently obvious in all cases, though in many cheapness is the explanation. In some things, as for instance small brackets and pegs, the patterns are new in their lightness and suitability for their intended

purposes. But in the case of many things, the reason for the preference which English ironmongers plainly show for American goods is not superficial. It is not altogether the lowness of price at which he can buy the goods, for the low price at which he sells them prevents any heavy profit. The real reasons are, however, not far to see. To begin with, hardly any English small castings are anything like as fine in surface, light in pattern, and cleanly turned out as are these American things. Small English castings often show the joint in the mould in which they are cast, fins are often not absent; and they are either turned out uncoated, or are daubed with a common black or dipped into a commoner. Most often screw holes are too large or too small. The countersunk part is large and flat, while the actual hole is small. Hence a small reamer is required to prepare the holes for the screws, and few carpenters would feel themselves prepared to go and fix a set of door and window furniture without a counter-sinking rose bit, and even then he must fix with screws with bright heads, which soon rust. All this the Americans have changed. Their castings are light, though strong in design, they are clean, and are touched up on an emery or grindstone, and are nicely coated with a clear brown varnish of great toughness and strength. The holes are almost invariably properly prepared to receive the screws for fixing. The screws themselves are colored to match the ironwork and, at the same time, prevent rusting. The holes, too, are arranged so that where the greatest strain comes there are the most screws. Now these are reasons which affect the purchaser only, but there are other reasons which affect the ironmonger, and which explain why he is so ready to show his customer the American articles. All the small articles to which we have referred are sent out by the English manufacturer done up in separate papers, or in paper packets tied up with string. Thus when the ironmonger wants even one article, or only wishes to show one to a customer, he has to undo a string, unfold paper or papers, do these papers up again, tie them, and re-arrange the label on the package. Instead of this old bungling way of keeping store and serving customers, the Americans supply their articles in paper boxes, sufficiently strong to last out the sale of the articles, one or two at a time. These boxes are easily and neatly stacked, the labels are fixed once for all, and to open one and show its contents, or take some out and reclose the box, is the work of a moment. This question is one of much greater importance than it at first sight appears. Folding up and re-tieing parcels is irksome and exceedingly uninteresting work, and is such as is not done very quickly at any time. Piles of packages, which have been taken down to show customers, collect on the counters to be done up "presently," because they cannot be done up while the customer is being served. These have to be done up, and some one must do it. Here is an important saving. One London ironmonger, whose sales in furnishing ironmongery in a moderate size shop consist of about one-half American articles, recently assured us that he had, from the saving of labor in this way, been able to dispense with about one-fourth the assistance he would otherwise have required for the increased business done in small articles. Again, not only do tradesmen and assistants appreciate the saving in time in serving customers, but the work is so very much cleaner for them, and the work of clearing up after closing is reduced almost to *nil*. The same ironmonger also assured us that ready as is the sale of these American articles, he is unable to get them as fast as he could wish. The receipt of the goods is irregular, and is not likely to be regular as those from English makers. He would therefore prefer buying of the English maker, if he would produce at the same price equally well designed and finished articles, packed as conveniently as by the American competitor. In a recent note we recorded the relative consumption of paper by the different nations of the world, and observed that the consumption per head of the American population was far in excess of that of any other country. Part of this excess is probably explained by the large use of paper in the manufacture of boxes for packing. These, of course, it may be said, only take the place of our paper, but this is not the case. A considerable number of articles are here wrapped up in very thin paper, and en-

closed in one strong wrap. The same article would in America, and by American factors, he sent out in boxes containing about a dozen, or dozen pairs of the same articles, and the boxes weigh more than the paper wrap. How much preferable the box system is may be acknowledged by every one, and before Americans satisfy English demand by regular supply, it will be well for our manufacturers to look about them, and produce clean, light, well-finished articles and apparatus, packed and delivered in a manner tempting not only to the consumer, but to the retail dealer. Are Englishmen to be beaten on their own ground in this way because men and masters cannot or will not depart from old errors of reasonless custom? There seems something of disgrace in the fact that the producers of another land should have, even so far as they have, taken the place of home producers? The retail ironmongers tell us, when speaking of the fine, clean, finished castings, that "the English cannot do it." Cannot do it! Surely to be told this ought to make some of the more energetic and ingenious of our manufacturers prove by works that it is false. To a certain extent it is false, for we know of founders who produce fine machinery castings of the most excellent cleanness and finish. This is, however, far from general, and though it is not true that English manufacturers cannot produce clean, fine, well finished, and cheap work, it is true that they cannot, or at least have not, produced it in accordance with that most important condition, price.

REPORTS OF ENGINEERING SOCIETIES.

ENGINEERS' CLUB OF PHILADELPHIA.—At the recent annual meeting the following gentlemen were elected officers of the Engineers' Club of Philadelphia, to serve during the year beginning January 11th, 1879:

President—T. C. Clarke; Vice-President—J. B. Knight; Corresponding Secretary and Treasurer—Charles E. Billin; Recording Secretary—Herman Hoops; Directors—William G. Neilson, D. McN. Stauffer, Rudolph Hering, Coleman Sellers, Jr., Percival Roberts, Jr.

AT the last meeting of the Northern Architectural Association Mr. W. H. Dunn read a paper on "Concrete." He described the many forms in which concrete could be used in building constructions, showing its adaptiveness for foundations and fire-resisting floors and roofing, and the possibility of a much more general application of the material. In accounting for the shyness which the public had entertained for concrete work, he thought that the early promoters had much to do with the false impression, their great argument being "cheapness and expedition," and this seemed rather characteristic of bad work. From his experience concrete was neither so very cheap nor yet so expeditious for house building, its virtue consisting more of "utility and usefulness," and, instead of being so expeditious, was in reality a slow setting material, and when treated in its true and legitimate way was most reliable. Under the section of "Flooring," Mr. Dunn referred to the several works in which he had introduced concrete for large spans, mentioning that he had recently executed a floor with a clear span of 21ft. by 18ft. 6in. without any intervening supports. In describing the application of different kinds of concrete, he stated that for malting working floors he had used a compound of riddled marl, slaked lime, and Portland cement, which, whilst forming a durable floor, also retained and gave moisture; thus assisting the growth of the malt. The paper was illustrated with working drawings of works in concrete he had executed.

AT the meeting of the Scientific and Mechanical Society, held recently, Mr. I. Bowes read a paper on the utilization of blast furnace slag and other waste products. After briefly alluding to the great saving now effected at many collieries by washing the small coal and making it into coke instead of burning it in the pit heaps as formerly, and to the useful products made from what was once the refuse of gas manufacturers, he spoke of what was now being done in the manufacture of useful commodities from blast furnace slag. About 30 cwt. of slag is made for every ton of pig iron, and in the Cleveland district alone from three to four millions of tons of this slag are made annually. Some millions of tons have been deposited on the banks of the River Tees and in forming an immense breakwater, which stretches out into the sea some miles at the mouth of the river. A few years ago Mr. Charles Wood, of Middlesbrough, Mr Woodward, and others, commenced making bricks, paving sets, concrete, and other articles from it, and two companies are now at work making these articles. About three millions of bricks are made annually, and sent principally to London by water carriage; and streets and crossings have been paved with these sets in several towns of the North of England. At some of the furnaces on the west coast the same articles have been produced from slag, and buildings, river walls, water courses, &c., constructed from the articles made. Glass works are now in operation at blast furnaces in Northamptonshire, where the slag is run direct from the iron furnace into the glass furnace, mixed with other materials, and then used for making bottles and other articles of glass. Mr. A. Jacob, borough engineer of Salford, is now using the sets to pave alongside the tram rails which are being put down in Eccles Old road.

IRON AND STEEL NOTES.

PROTECTION OF IRON FROM OXYDATION.—We have on many occasions drawn the attention of our readers to various devices suggested for preventing the oxydation which invariably occurs when iron is exposed to the action of the weather. The two latest of these, namely, those of Professor Barff and Mr. Bower, depend upon the production of a superficial coating of magnetic oxide, and, however excellent in their way, can scarcely be termed ornamental. When any other color than bluish-grey is required they are wholly inapplicable, and the material has to be painted in the ordinary way. We have lately had submitted to us some specimens of ironwork, suited to the most exacting requirements of ornament, and at the same time capable of withstanding, apparently for many years, the action of the weather, prepared by a process invented by Mr. J. B. A. Dodé, of Paris, which seems to promise exceedingly well for those many cases wherein ornamental effects are desired as well as simple protection from corrosion. For example, the railings surrounding the British Museum, and the lamp-posts of new designs used in the City, are periodically painted and gilt at short intervals, the expense, in comparison with the effect and durability, being enormous. It has often struck us, while watching the elaborate and tedious process of gilding ironwork in the open air, that some less wasteful method ought to be adopted. Such a method is certainly that we are about to describe, and without saying it is the best, we are bound to say it is a good one, and has satisfactorily stood every test we have applied. As a new process it has yet to prove how time and weather affect it; but when this is done there is little doubt that "platinized iron" will become as familiar a term as "oxidised iron."

The principle of Mr. Dodé's method is to coat the surface to be protected with a thin film of borate of lead having a little oxide of copper dissolved in it, and having also suspended in it bright scales of precipitated platinum. A red heat is employed to fuse the composition, which is either applied with a brush or employed as a bath, in which small articles may be dipped. Its effect is, to cover the iron with a thin glassy coating of a bright grey tint, not far removed from that of polished iron itself, and unaffected by sewer gases, dilute acids and alkalis, and the heat of a kitchen fire. Modifications of the composition give the means of imparting different colors to the coating, and these are as easy of application as the platinum grey just mentioned. The effects are really very good, and show how ornamental an iron grating of neat pattern, or an iron frieze might be in front of a gallery in a large building, or in any equally elevated position. There is, too, an opportunity for the City or Cathedral authorities to venture upon an experiment which deserves trying. The railings round St. Paul's Cathedral are to be redecorated, simultaneously with the improvement of the churchyard. Instead of adopting the present expensive method of gilding, why not coat them with Mr. Dodé's composition, at (we are informed) about $\frac{1}{20}$ of the cost?

Cost is in all cases a most important feature of preservative operations. We are told that the cost of platinizing is about equal to that of applying three coats of paint, and about one-tenth of that of electro-plating with nickel. These statements have reference to Paris prices, which as a usual rule are not lower than English. A detailed account of the treatment of eight stoves is as follows:—

	fr.
1 litre preparation (retail)	3.75
1st furnace operation	3.20
Reagents for platinizing	4.00
2nd furnace operation	3.20
Manipulation, wear and tear, &c.	1.85
	16.00

Or 2 fr. per stove. The trade is quite willing to pay four times this rate, as to electro-nickel a stove costs from 32 fr. to 40 fr. For some special manufactures the new process appears to promise particularly well, and we understand that the Val d'Osne Company have expressed a highly favorable opinion of it. Such manufacturers, who can treat their castings before they cool, will find a still further economy in what already seems to be a very cheap and efficient process.

RAILWAY NOTES.

A PORTUGUESE railway of considerable importance, known as the Beira Alta Railway, and forming a junction with the Northern Railway at Pampilhosa, is about to be built. It will cross the Busaes range, pass through the valley of the Mondega to Guarda, and terminate at Villar Formosa, on the Spanish frontier. The total length of the road will be only 125 miles, but the line will be important because it will open up a fertile and well populated district, at present without any railway facilities, and also form the missing link of the direct or international route between Lisbon and Paris by the north of Spain. The present railway communication between the two capitals is 1449 miles in length, while by the Beira Alta line it will be only 1171 miles, or 273 miles less. The contract for its construction and working has just been given to the Société Financiere of Paris, which binds itself to open the road in four years. The Portuguese Government grants a cash subsidy of £8225 per mile, the total estimated cost being £11,719 per mile. For this and other aid, in the way of lands and buildings, and exemptions from duties and imposts, it will exact a "transit duty of five per cent. on fares for freight and passengers."

SOME interesting statistics have recently been published on the railways of the world, by Prof. Neumann-Spallart, of Vienna. During the last three decennial periods the length of the railroads in Europe has risen from 9000 kilometers to 154,200. In that total the share of Germany is 30,000 kilos.; Great Britain and Ireland, 27,500; Austro-Hungary, 24,800; France, 23,400; Russia, 18,000, &c. The result is that in this quarter of the world the number of kilometers of lines is 150 to each superficies of 1000 square kilos., and 4 4-5 kilos.

per 10,000 inhabitants. Those averages are, however, exceeded in Great Britain, Belgium, France, Switzerland, Holland, &c. In America, the United States commenced in 1830 with 42 kilos.; at present they possess 128,000, or 133 per 1000 square kilos, and 28 per 10,000 inhabitants. The professor, however, states that this result has been attained by a loss to the shareholders of 4,000,000,000 marks (1f. 25c.) from 1872 to 1877. The other States in that part of the world only possess 17,000 kilos of railway, of which 7000 belong to Canada. In Asia, China remains closed to that system of communication, while British India, including Ceylon, has 11,000 kilos., or 46 per 1000 square kilos., and half a kilo. per 10,000 people. Africa has 2800 kilos., of which 1800 belong to Egypt. Australia has 4000 kilos., principally situated in the part of the continent which contains the colony of Victoria, then Tasmania, and finally New Zealand. In Oceania, Otaheite has a little railroad. The capital invested in all the railroads of the globe exceeds £3,500,000,000. Those lines dispose of 62,000 locomotives, 112,000 passenger carriages, and 1,500,000 goods trucks. They carry yearly 1,500,000,000 persons and 1,600,000,000 tons of merchandize annually.

THE Federal railway department has recently published an interesting and elaborate statement of the position of the Swiss railways in the years 1874 and 1876. In the former year the total length of railways in the territory of the confederation was 1020 miles; in 1876, 1472 miles, being an increase of 452—nearly 50 per cent. The principal lines are the Aargau Wohlen-Bremgarten, with 215 miles; the Jura-Berne-Lucerne and the Boedeh, which, together with the Berne State lines, count 318 miles; the Swiss North-Eastern, 319 miles; the Swiss Western and its subsidiary lines, 351 miles; and the Swiss Union, with the lines Toggenbourg and Wald-Ruti, 195 miles. The remaining mileage is made up of ten smaller lines from the Rohrshach-Heiden and the Uethberg, with their five miles each, to the Gothard and the Swiss National, with their forty and forty-seven miles respectively. In this list are included only lines that were actually working at the time in question—the 31st December, 1876; but the increase since that date is not considerable. The cost of constructing these lines is put down at £33,606,300, and the capital employed in working them at £28,728,000. The rolling stock consisted of 549 locomotives and 1662 carriages, capable of accommodating 73,243 passengers; and 8352 wagons, with a carrying capacity of 84,605 tons. The distance run by these 549 locomotives in 1876 was 8,857,550 miles—14,310 miles each. The material served to transport 23,815,207 passengers, 82,036 tons of luggage, 694,694 head of cattle, horses and dogs, and 5,669,364 tons of merchandize. The receipts from passenger traffic amounted in 1874 to £831,200; in 1875 to £928,948; and in 1876 to £976,800. The total receipts from all sources, in which 1874 reached £2,086,000, had increased in 1876 to £2,427,240; but this increase was far from being commensurate with the increase in mileage; for, whereas in the former year the total receipts per kilometer were £1375, they had sunk in 1876 to £1141 per kilometer. It is a notable fact that in late years there has been a steady diminution in the number of passengers traveling first-class, and an increase in the numbers of those traveling second and third-class. In 1876, out of every 100 passengears 6.99 took first-class, 33.63 second-class, and 59.38 third-class tickets. It is stated that the market value of eighteen companies, with an aggregate paid-up capital of 43 millions sterling, does not exceed 23 millions—a depreciation of 20 millions—an enormous loss for so small a country as Switzerland.

IMPROVEMENT IN RAILROAD TRACKS.—Anaxamander Herring, of Cohoes, has invented a new and useful mode of securing an elastic railroad track or bearing, and destroying the effect of the percussive force of railroad cars upon the rails and supports, and upon the cars.

The nature of the invention consists in the employment of sand between the parts of the pillow-blocks which support railroad-rails on iron bridges, or elevated railways.

By this invention an elastic track on iron bridges can be secured without the aid of metal and rubber springs or combustible materials, such as wood; at the same time the effect of the percussive action of cars upon the metal railroad-bridge heretofore experienced is destroyed; the shaking and loosening of the parts of the bridge structure, as well as the jarring of the rail-cars is also avoided, this result being due to the fact that the sand serves to absorb the blows due to the weight and motion of the cars as they roll over the track, while it serves to effectually deaden the sound experienced in elevated railways.

Mr. Herring's claim is as follows:

1. Sand as a cushion for railroad-rails, carbodies, and other analogous uses, applied between the upper head of a drum or chamber, and a piston.

2. Sand as a cushion for rails and other objects, applied between the heads of a drum or chamber, and the upper and lower ends of a piston.

3. The drum or chamber, packed with sand and provided with a piston, the stem or rod of which is fastened to a foundation, and having a railroad-rail shoe or chair formed on its upper head.

4. The drum or chamber packed with sand and provided with a piston, and having sand-supply holes.

ENGINEERING STRUCTURES.

THE AVONMOUTH DOCK.—At the meeting of the Institution of Civil Engineers, held on Tuesday, November 12, the first paper read was on "The Avonmouth Dock," by Mr. J. B. Mackenzie, M. Inst. C.E.

Bristol at an early period of history was one of the chief shipping ports in the kingdom. Down to the era of ocean steamers, it was accounted only second in importance to the port of London, but subsequently declined to a comparatively subordinate rank. The paper de-

scribed various schemes by different engineers for the improvement of the port from the time of Smeaton to the year 1860, of which only one by Jessop had been carried out. In 1864, Mr. Brunlees, Vice President Inst. C.E., recommended a scheme for a dock at the mouth of the Avon, which had been previously suggested. It was undertaken by the Bristol Port and Channel Dock Company in 1868, and was completed in 1877. The dock was on the Gloucestershire side of the Avon; from the anchorage of King Road in the Bristol Channel to the entrance lock, the distance was only 1,000 yards. The entrance channel from the Avon to the lock was about 350 yards in length by an average width of 70 yards, with a depth at high water of equinoctial spring tides of 44 feet, and of 40 feet at ordinary spring tides. The dock was 1400 feet in length, and 500 feet in width, giving a water area of about 16 acres, and a length of quay wall of 3200 feet. The south end was not protected by a wall, but was finished off with a slope of 2½ to 1. The range of an ordinary spring tide was 39 feet, while that of an ordinary neap tide was 19 feet. A special feature of the tides was the quantity of mud which the water held in suspension. The complete silting up of the old entrance of the Avon a few years ago, and the opening of the present Swash Way, was a striking example of mud settlement and accumulation. A temporary embankment, to exclude the tide during the construction of the works, was made by tipping silt excavated from the dock over the ground. A wooden truss was used to exclude the tide while the outer clay dam was being removed. It proved satisfactory; and the leakage from the tide was easily kept under by a small force pump. The mouth of the lock had a wing wall on each side, extending about 159 feet beyond the roundheads, and diverging from a line parallel with, and 100 feet distant from, the center line of the lock, at an angle of 11 deg. 30 min. Rubble masonry faced with rough ashlar was employed. The walls were 49 feet in height from the top of the footings to the coping, 23 feet 6 inches wide at the base, and 7 feet wide at the top. The face was battered to a radius of 150 feet, and the back had two steps 18 inches and two 12 inches wide. The footings were also of rubble masonry, and rested on sand; the inverts were of brick. The clear length between the inner and the outer gates was 454 feet. This length was divided by a pair of gates into two locks, the inner one being about 50 feet longer than the outer one. The foundations of the lock were laid upon a bed of fine gray sand underlying clay at an almost uniform level, and at a depth of about 6 feet under low water of equinoctial spring tides. The frequent occurrence of springs in this sand was a source of some trouble and difficulty. The apron in front of the lock was a mass of lime concrete, mixed with blocks of stone of 2 tons to 3 tons weight, and surrounded by walls of Portland cement concrete. The lock gates consisted of oak heel and mitre posts, except the outer pair of gates, which were of greenheart, with ribs, intermediate posts, and walings of pitch pine and Memel. The gates were 2 feet 8 inches thick at the heel and mitre posts, and about 2 feet 11 inches thick at the center of the leaf, exclusive of the walings. The back of the gates, when shut, formed a continuous arc of a circle from one hollow quoin to another, the radius of which was 50 feet. The ribs and intermediate posts of the upper gates were differently arranged to those of the middle and outer gates. The height of the dock wall was 40 feet, and the depth of the foundations below the dock floor varied from 2 feet 6 inches to 19 feet. The footings were of lime concrete 22 feet 6 inches in width, and were carried up 2 feet above the dock floor. From this level to the top, the wall was built of rubble masonry, faced with dressed stone. Two failures of parts of the dock wall, caused by the wall slipping forward and sinking, were then described, and the remedial measures pursued, also the modifications introduced in the subsequent work. The earthwork chiefly consisted of clay. Upwards of 1,750,000 cubic yards of material were shifted from the dock basin, lock, entrance channel, and foundations. Of this quantity, about 150,000 cubic yards were dredged from the entrance, and discharged from hopper barges, at a shallow part of the Bristol Channel, about three miles from the works. The average cost of the excavations, including a portion of the pumping expenses, was about 1s. 6d. per cubic yard. The average price for rubble masonry was about 20s. per cubic yard. The Portland cement concrete consisted of one part of Portland cement, three parts of sand and gravel, and five of stone broken to a small size, and the whole mixed with large blocks of stone. The average price of this concrete was about 16s. per cubic yard. The lime concrete used for the foundations was mixed in the proportions of six to one, viz., one part of lime, two parts of sand, two of ashes, two of broken stone, and cost about 10s. per cubic yard.

DARIEN CANAL.—An interesting lecture was recently given by Rear-Admiral Dan'l Ammen, U.S. Navy, before the American Geographical Society in New York, "On the proposed Inter-Oceanic Ship Canal across the American Isthmus." The Admiral stated that after an examination of the reports of Lieut. Wyse of both seasons, he was confirmed in the opinion expressed in a paper previously presented to the society "that no possible route exists comparable with what had been presented in the surveys made by order of our Government." The able reports of Commander E. P. Lull and Civil Engineer A. G. Menocal, U.S. Navy, on the Nicaragua route, are, he said, "sufficiently full for examination and criticism by the civil engineer or the expert. There has been given throughout a careful consideration to that vital question in the construction of an inter-oceanic ship canal in that region—an ample and studied provision to prevent any considerable quantity of surface drainage entering the canal, and the feasibility of accomplishing this object on the located route, as compared with other routes, is, in my belief, a most important point in its favor." In conclusion, he said: "To the courage, devotion, and ability of cultured officers as leaders, and to their assistants, we are

indebted for much substantial information. It is impossible for any one having no personal knowledge of the Isthmus to appreciate the difficulty of making surveys in that region." A summary of distances and estimates of cost, as given in the report of Civil Engineer Menocal, is as follows:—Western division, from Port Brito to the lake: Distance, 16.33 miles, estimated cost £4,337,555. Middle division, Lake Nicaragua: Distance, 66.50 miles, estimated cost £143,131. Eastern division, from lake to Greytown: Distance, 108.43 miles, estimated cost £5,005,200. Construction of Greytown harbor, £457,126. Construction of Brito harbor, £567,746; total, £10,515,543. A true economy, however, will be to consider the cost of the canal, including the interest on dormant capital, as double the estimated cost, in round numbers at £20,000,000.

ORDNANCE AND NAVAL.

ARTILLERY TESTS.—Artillerists, whose judgment could not be ignored having expressed the opinion that with the new 4-ton 6-inch Armstrong gun-hitting power almost equal to that of the 9-inch gun of the service could be obtained, a series of experiments has lately been made for the purpose of testing the accuracy of the view.

The first round was fired with a shell of Whitworth steel, weighing 80 lbs., with a charge of 33 lbs. This gun, when fired for velocity only, had 70 lbs. and 64½ lbs. projectiles, the calibre being that of the 64-pounder gun of the service. With these projectiles velocities of 2,000 feet per second and 2,070 feet per second were attained respectively, and that with a very light strain on the gun—namely, 15 tons per square inch. In adding 10 lbs. to the weight of the shells, a less velocity with the same charge would necessarily be attained. The velocity with 33 lbs. and an 80 lbs. shell was 1,792 feet at the point it had reached when its speed was taken. This was rather less than the muzzle velocity, which may be put at 1,800 feet. Its target was an unbacked plate 10 inches thick. The steel shell passed completely through the plate and buried itself 8 feet in the sand behind it. If we suppose that the force which remained in the projectile and carried it 8 feet into the sand was sufficient to have overcome the resistance due to one more inch of iron—and this is most probable—we have a gun of only 4 tons throwing a shell of 80 lbs. weight with a force sufficient to pierce by far the larger number of ironclads now afloat. The hole made in this plate was 6.04 inches in diameter, and the shell was hardly at all altered in shape. Nothing could be more satisfactory as to the quality of the metal; and another fact of great interest presented itself. The gas check was found to remain firmly attached to the shell, though it had passed through 10 inches of solid iron.

For the second round another shell of Whitworth steel was taken, and the charge was 36 lbs., instead of 33 lb. as in the first round. The additional 3 lb. of powder raised the velocity of the projectile to 1,887.5 feet per second at the point where the observation was made. The initial velocity would, therefore, have been nearly 1,900 feet. This ought to have given a penetration of about 11 inches into the plate. But, unfortunately, the quality of the steel was not equal to that of the first shell. Instead of retaining its form, the projectile set up considerably, thus wasting, in the alteration of its own form, the power that ought to have been spent upon the plate. The result was a penetration of only 9.6 inch. No certain argument can be drawn from one misfortune; but, so far as it went, the opinion of those who object to the expensive steel projectiles was confirmed. A long series of rounds must be fired before any definite conclusion can be drawn. It is possible, however, that steel shells may be found superior to iron when the target is within their power to pierce, but inferior in effect when the iron plate resists complete penetration.

The third round was fired with exactly the same charge as the first—33 lbs., and the weight of the projectile was also the same (80 lbs.); but it was of chilled iron instead of Whitworth steel. The velocity was rather higher—1,819 feet against 1,792 feet, a difference hardly appreciable. The effect was equal as far as could be judged. The plate was easily penetrated, the diameter of the hole being 6.06 inch. The head of the shell was found in the sand entire, save that the extreme point was broken off. The body of the shell was broken into numerous pieces, which all passed through the plate. The advocates of chilled iron shells assert that, though they always break up in passing through strong iron plates, the penetration is not affected thereby to any appreciable extent; for, as the hardness of the metal prevents the shell from setting up—that is, bulging—the pieces keep together and act as a whole while passing through the plate. We should be sorry to speak dogmatically on such a subject, but we cannot believe that no force is lost in breaking up the shell. Something must be wasted, but that something may be very small, especially as it is known that the tension existing in a chilled shell is sometimes sufficient in itself to break up the mass even without the shock of striking an iron target.

However this may be, the fourth round gave results which must be deemed satisfactory by all who hold to the chilled shells of the service. This time a charge of 36 lbs. was used, as in the second round, and the weight of the shell, as usual, was about 80 lbs. The observed velocity was 1,919 feet per second, and the target was beyond the power of the projectile to penetrate, being an unbacked plate 12 inches thick. The behavior of this shell was very interesting. As usual, it broke up; the head, without altering its form, rebounded 30 or 40 feet from the plate, which it could not entirely pierce. The body of the shell broke up into five or six pieces. But when the effect on the target was examined it was found that the projectile had penetrated no less than 11.3 inches, against the 9.6 inch of the Whitworth steel projectile in the second round, and that the back of the plate was

cracked in front of the hole. Little more force would have been required to complete the penetration of the target, and the effect produced was almost exactly the same as that obtained by firing the 9-inch service gun of 12 tons with a charge of 65 lbs. of powder. In order to show clearly the progress made by Sir William Armstrong in the construction of guns, let us place these two pieces in juxtaposition :—Service gun—12 tons weight, 9-inch calibre, 65 lbs. charge, 250 lbs. projectile; new gun—3 tons 18 cwt., 6-inch calibre, 36 lbs. charge, 80 lbs. projectile. If we carry back our thoughts a few years and remember that the heaviest gun in the service, the 68-pounder of 5 tons 12 cwt. could make no impression on the 4.5 inch plates of the early ironclads, and that in 1866 the Austrian ships carried ordnance which were totally ineffective against the Italian vessels, the sides of which were pitted with the marks of shot fired at close range, we shall see how extraordinary has been the development of the art of destruction. The most interesting comparison that could be made with ordnance that were actually supported by artillerists in America, and even by some in our own country as late as 1867, would be that of the 15-inch American smoothbore with the new 6-inch Armstrong. The American gun weighed 19¼ tons, nearly five times as much as the 6-inch. Its charge was 60 lbs., or, as an extreme case, 100 lbs. With 60 lbs. the shot (for no round shells could be used against plates) was utterly foiled by the 8-inch target, and with 100 lbs. it succeeded in penetrating it. The little 6-inch of less than 4 tons would pierce that target with ease, as the 9-inch service gun did.

RECENT ADDITIONS TO THE BRITISH NAVY.—One of the most powerful armor-plated ships afloat was added to the list of vessels composing Her Majesty's navy by the purchase from the Thames Ironworks Company of the steam-ram, Memdouhiye, built for the Turkish Government, but detained for the last twelve months as contraband in the Victoria Docks, Blackwall. The vessel was handed over by Sir Peter Rolt, chairman of the Ironworks Company, and Captain Comyn, who has had charge, and was to have taken the vessel out to Turkey, delivered over his command to the representative of the Board of Admiralty. As a ship of the Royal Navy, she is to be named the Superb. Her length is 340 feet, and her beam 60 feet. She carries a raised fighting battery amidships, and the battery, which is about 100 feet by 60 feet, is pierced for twelve 18-tons guns. The guns are not on board, but in other respects she is quite ready for sea. The battery is covered with 12-inch wrought-iron plates on the usual teak backing, carried down some depth below the water-line, and raised only a few feet above what appears to be the main deck, but is really only a spar deck of unarmored timber. The true main deck is below, and is made of iron, the saloons and quarters for officers and men being upon it, but it is assumed that in time of action all hands will be in the armored enclosure, leaving the unarmored portion to its fate. The hatchways of the main deck close by water-tight iron doors, and there are upwards of sixty water-tight compartments in the lower decks and the double iron skin. It is proposed to mount four 12-ton guns on the main deck, which is about 6 feet clear of the water, the battery guns having a freeboard of 10 feet. The engines are by Maudslay and Field, and are on the direct-action principle, and of 7,000 horse-power. The ship is fitted with Paul's steam steering gear, worked either from the pilot tower on the upper deck or between the battery, with hand-gear and reserve appliances in case of accident. The steering apparatus is very powerful, and the ship is said to have behaved splendidly in her trial trip. Her saloons are spacious and handsomely furnished. She resembles the Alexandra, the flagship of the fleet in the Mediterranean, except that the Alexandra has a double battery with two 25-ton guns in the upper portion. The Superb has a burden of 5,349 tons, and will require a ship's company of 800 officers and men. Seen afloat, only the upper swell of her prow is visible, but the ram extends some distance under water. Another valuable ship will shortly be added to the effective strength of the navy, the Triumph having undergone a comprehensive overhaul and refit at Portsmouth. She has been furnished with an entirely new set of boilers from the Keyham yard, and her machinery has been thoroughly repaired and renovated by the contractors, Messrs. Maudslay, Sons and Field. The old cylinders have been removed and new cylinders and cylinder covers have been fitted, the bearings have been adjusted and refitted with white metal, the condenser tubes have been taken out and examined, and the whole of the copper piping has been tested and renewed where found to be necessary. The superheater, which is gradually being superseded in our men-of-war, has been removed, and a fresh-water donkey engine has been added to her complement of engines by Messrs. Brotherhood and Hardingham. The hull of the ship has also undergone important changes in order to bring her up to the requirements of modern warfare. She has been, for the first time, fitted with the Whitehead torpedo, two special ports having been cut in each bow and the usual racers and overhead gear provided for the carriages and the transport of the projectiles from below. The torpedo engine was manufactured at the Portsmouth yard. A Gatling gun has been placed on the foretop in addition to the one which she carried throughout her late commission in the Mediterranean in the maintop; and, as a further protection against the attacks of boats and small craft, she has been armed with four 20 pounder torpedo guns, which are mounted on the spar deck amidships. Shell gratings have been fitted in the wake of the boilers, in order to prevent fragments intruding into the stokeholes and disabling the machinery. The block compressors on the main deck have been removed, and new cable controllers have been fitted on the upper deck, the coal bunkers have received additional ventilation, and the steam steering gear and the steam capstan have had all their defects made good. As the shell for the 12-ton guns has been lengthened to the ex-

tent of 2 inches, this alteration has necessitated important readjustments being made in the shell-room for the storing of the new projectiles. The other changes which have been effected mainly consist of the cabin rearrangements, which were necessary to convert the Triumph into an admiral's ship. The cost of repairs and improvements to the hull alone amounts to something like £20,000. The ship made a six hours' continuous full-power trial of her main engines, which are of the return connecting-rod type, with surface-condensers and work with steam at 30 lbs. pressure. The new boilers, considering the state in which they were found on the preliminary trial, behaved pretty well, a little priming only being exhibited at the beginning. Notwithstanding, however, the fact that the blast was kept wide open during the six hours, considerable difficulty was experienced in maintaining a full head of steam, and during the latter part of the trial it was deemed expedient to raise the links and work the steam more expansively. The new bearings also gave a little trouble. The average pressure of steam in the boilers was 27 lbs. to the square inch; the mean vacuum recorded was 26.4 inch in the forward, and 27.9 inch in the after condenser; the mean pressure of steam in the cylinder was 15.27 lbs.; and the mean revolutions per minute 63.46. The maximum power developed was 4,287 horses, but at one time it fell as low as 2,859. The mean indicated power developed was 3,556.61, and the approximate speed realized 12 knots. The trial, which was under the superintendence of Mr. Warriner and the officers of the Portsmouth Steam Reserve, was considered scarcely satisfactory.

BOOK NOTICES.

THE TRANSMISSION OF POWER BY COMPRESSED AIR. By ROBERT ZAHNER, M. E. New York: Price 50 cts.

This important subject is treated with sufficient fullness to satisfy the wants of the practical engineer within the limits of this small volume. The essay which is reprinted from Vol. XIX of this Magazine forms No. 40 of the Science Series.

The use of compressed air as a motive power is rapidly extending, but is yielding results that are far short of what is to be expected, when the theoretical conditions are well understood.

This *petite* volume is well designed to prepare the way to a better knowledge of so much thermodynamics as is involved in the practical problem.

THE COMMERCIAL PRODUCTS OF THE SEA. By P. L. SIMMONDS. London: Griffith & Farran. Price $8.00.

This octavo of 490 pages is full of interesting information respecting the marine contributions to food, industry and art; these three divisions of the subjects being treated separately as "parts" of the work.

The Food Products are, of course, the results of the many so-called fisheries and are numerous and wide spread.

The Industrial Products include Sponges, Shells, Fish Oils, Sea Weeds and Salt.

The contributions to Art are represented by Pearls, Corals, Tortoise-Shell and Amber.

The illustrations are good and the statistics seem carefully prepared.

THE GEOLOGY OF NEW HAMPSHIRE. By C. H. HITCHCOCK. Concord, N. H.: E. A. Jenks. Price, $40.00.

Vol. III of this work alone is of recent publication. It contains a valuable contribution to general Lithology.

The entire work, consisting of three large volumes and an unwieldy Atlas, will be regarded with more interest than State Reports usually are. It is an invaluable contribution to the sciences, if we may use the plural, of Geology, Lithology, and Physical Geography.

The maps are beautifully clear and many of the illustrations in the text represent the best style of pictorial printing.

INSTRUCTIONS FOR TESTING TELEGRAPH LINES. Vol. I. By LOUIS SCHWENDLER. London: Trübner & Co. Price $4.00.

This work is designed particularly for practical telegraphers but may be read profitably by all students of Electrical Science.

The requirements for applications in any use of Electricity involve an acquaintance with the principles demonstrated and fully illustrated in this book, as may be seen by this abstract of the contents. Wheatstone's Bridge, its sensibility; best practical management; Differential Galvanometer; explanation of the method; sensibility of the method; measurement of its resistances; best practical arrangement. Line testing; Regular testing; fault testing.

The Appendices treat of Ohm's Law; Kirchoff's Corollaries; Cable Testing, etc.

The typography of the book is excellent.

LEISURE-TIME STUDIES. By ANDREW WILSON, Ph. D. New York: R. Worthington.

This is a series of pleasant essays, chiefly upon biological subjects. All are profitable reading, and nearly all will prove exceedingly interesting to the general reader, if he have in the slightest degree a liking for natural history.

To the young inquirer after scientific facts, nothing could be more profitable than such essays as: A Study of Lower Life; The Sea Serpents of Science; Some Animal Architects; What I Saw in an Ant's Nest; and a Summer's Day.

A few good illustrations embellish the work.

A MANUAL FOR ENGINEERS AND STEAM USERS. By JOHN W. HILL, M. E. Providence: William A. Harris.

A good deal of valuable information is condensed into this compact little volume. That the information is of the right kind for all interested in employing steam, and that the rules, formulæ and tables are accurate, is sufficiently attested by the statement that it is prepared by Mr. Hill, the well-known expert, of Cincinnati.

The book is the property of Mr. William A. Harris, and is designed chiefly as a guide to those who use the Harris-Corliss engine.

MISCELLANEOUS.

TELEPHONIC DETERMINATION OF THE MAGNETIC MERIDIAN.—M. H. de Parville substitutes a bar of soft iron at least 1 meter (39.37 inches) in length for the short magnet of an ordinary telephone. The apparatus still transmits sounds, but with an intensity which varies with the direction of the bar, the sound being most intense in the receiver when the transmitter is parallel to the dipping needle. The sound is more or less completely extinguished when the transmitter is perpendicular to the magnetic meridian. If such a telephone is provided with a resonator it can be used not only to find the direction of the magnetic needle, but also for the approximate determination of the variations in magnetic intensity. This method seems applicable, on shipboard, for the correction of the compass, especially when the indications of the needle may be deceptive on account of the neighborhood of magnetic rocks or of islands rich in iron ores. The inventor also suggests the use of a bar of soft iron several meters in length, having at one end a magnetic coil with a self-registering apparatus. The pitching of the vessel would excite induction currents, and the diagram on the register would reveal the direction of the vessel so as to check the indications of the compass.—*Comptes Rendus.*

ELEPHANTS FOR AFRICAN TRAVEL.—The *Academy* notes that a successful experiment has lately been tried in the equatorial provinces of Egypt, which may not improbably ere long revolutionize the mode of transit in Eastern Africa, and solve a problem which has hitherto puzzled travelers. About a year ago, at Colonel Gordon's request, a few trained elephants were sent to Khartum, where they arrived in due course, having marched along the banks of the Nile. A report has been received in Cairo from Colonel Gordon stating that he had despatched them to the military station of Lardo, about 11 deg. south of Khartum, and six miles north of Gondokoro, and that they had accomplished this distance in 84 days. A not unimportant advantage to be derived from the employment of elephants in this manner was demonstrated by the fact that the negroes along the line of march were frightened by them, and made no attempt to attack the party. The elephants have gradually learned to live on leaves and grass, as the wild elephants do, and keep in first-rate condition without the different kinds of food to which they had previously been accustomed. Colonel Gordon consequently advises travelers going into the interior of Africa from Zanzibar to use elephants, and thus to avoid the necessity for a host of porters, who are a never-ending source of delay and annoyance. It may be remembered that the question of employing elephants in African exploration was discussed after the reading of Mr. H. B. Cotterill's paper on the Nyassa, for the Society's African Section on the 28th of May last.

THE employment of alkaline manganates for imparting to light woods in furniture and floors an attractive, uniform, and durable walnut brown, is highly recommended by M. Viedt. The action depends upon the decomposition of salt in the pores of the wood, with the separation in them of very finely-divided brown hydrate peroxide of manganese, and an addition of magnesium sulphate to the solution is found to hasten the reaction. In practice, the following method is said to be successful. Equal parts of manganate of soda and crystallized Epsom salts are dissolved in twenty to thirty times the amount of water, at about 144 deg., and the planed wood is then brushed with the solution; the less the water employed, the darker the stain, and the hotter the solution, the deeper it will penetrate. When thoroughly dry, and after the operation has been repeated, if necessary, the furniture is smoothed with oil, and finely polished, the appearance being then really beautiful. Before smoothing, however, a careful washing with hot water will have the effect of preventing the efflorescence of the sulphate of soda formed. In the treatment of floors, the solution may be employed boiling hot, and, if the shade produced is not dark enough, a second application of a less concentrated solution is made; after it is quite dry, it is varnished with a perfectly colorless oil-varnish. On account of the depth to which the coloring solution penetrates a fresh application is not, says the *Lumber Gazette*, soon required.

ONE of the most suggestive illustrations that can be adduced as showing the advances made within the last forty years in marine engine economy is derivable from an examination of data of recorded averages of Atlantic steamships; and more especially of those of the Cunard paddle-wheel steamer Britannia, in 1840, and the White Star screw steamer Britannic in 1877. Of the first vessel the average duration of passage was fourteen days and eight hours, and the consumption of fuel 544 tons, the daily consumption thus being 38 tons. Assuming the average cargo at 225 tons, this gives 48.35 cwt. of coal per ton of cargo; and the average speed in knots per hour being 8.3, the consumption per knot was 3.8 cwt. The indicated horse-power was 740, and consumption per horse-power, 4.7 cwt. The Britannia displaced but 2,050 tons, and this must be taken into account in comparing her with the Britannic, whose displacement is more than four times as great, or 8,500 tons. That vessel, in 1877, showed an average passage of seven days ten hours and fifty-three minutes, an average daily consumption of fuel of 100 tons, or total consumption of 745 tons. Her cargo is 3,350 tons; consumption of fuel per ton of cargo, 4.45 cwt.; average speed, 15.6 knots; consumption per knot, 5.3 cwt.; indicated horse-power, 4,920; consumption per horse-power, 1.9 cwt. In other words, we are now enabled to transport fifteen times as much freight across the ocean in one-half the time at an expenditure of less than one and a half times as much coal as in 1840.

—*The Engineer.*